Plate 1 of 2
Utah Geological Survey Open-File Report 586DM
Interim Geologic Map of the Provo 30' x 60' Quadrangle

UTAH GEOLOGICAL SURVEY
a division of
Utah Department of Natural Resources

INTERIM GEOLOGIC MAP OF THE PROVO 30' X 60' QUADRANGLE, UTAH, WASATCH, AND SALT LAKE COUNTIES, UTAH

by
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2011

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SCALE 1:62,500
CONTOUR INTERVAL 50 METERS

1 0.5 0 1 2 3 4 MILES
1 0.5 0 1 2 3 4 5 6 KILOMETERS

QUADRANGLE LOCATION

APPROXIMATE MEAN DECLINATION, 2011

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This geologic map was funded by the Utah Geological Survey and U.S. Geological Survey, National Cooperative Geologic Mapping Program through U.S. Geological Survey STATEMAP Agreement Numbers 99HQAG0138, 01HQAG100, 02HQAG055, 03HQAG0096, 04HQAG0040, 05HQAG0084, 06HQAG0037, 08HQAG0096. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Geologic Units

Qh	Qgo?	Tvc	Ppf
Qa	Qgmo	Tucb	Ppm
Qay	Qgao	Tuc	Ppg
Qam	Qfdp	Tu	Pdc
Qam?	Qdp	Tgu	Pk
Qao	Qfdb	Tgm	PIPo
Qal	Qdb	Tgl	Pofc
Qat	Qlg	Tc	PIPgw
Qat1	Qls	Tf	Pogm
Qat2	Qlf	Ts	Pogm?
Qat2?	Qll	Tn	Pogml
Qat3	Qly	TKnq	IPobm
Qaty	Qla	TKn	IPobm?
Qaf	Qes	TKc	IPowr
Qafy	Qst	Kpc	IPos
Qaf3	Qa/Qst	Kmv	IPobp
Qafp	Qsm	Km	IPobl
Qafb	Qrc	Kf	IPobc
Qafm	QTst	Kmm	IPobc?
Qafm?	QTa	Kd	IPowc
Qafmo	QTaf	Kcm	IPobv
Qafo	QTaf?	KJcm	IPw
Qafo?	QTmb	Jsv	IPrv
Qac	QTmb(Pogm)	Js	Mmc
Qc	QTmb(PIPo)	Jce	Mmc?
Qct	QTmb(IPobc)	Jp	Mdo
Qmc	QTmb(IPobv)	Ja	Mdot
Qmt	QTmb(Mmc)	Jtc	Mgb
Qmd	QTmb(Mgb)	Jtu	Mgbu
Qmf	Taf	Jtgl	Mgbsl
Qmdf	Taf?	Jtwl	Mh
Qms	Tsl	Jtw	Mde
Qms?(IPobc)	Tb	Jtl	Mde?
Qms?(Mmc)	Tic	Jtb	Mgf
Qmsy	Tict	Jtrsg	Mg
Qmso	Tvtw	Jn	MDfp
Qml?	Tsp	TRa	Cote
Qmg	Ti	TRau	Ccte?
Qg	Tt	TRam	Cmo
Qg?	Tt?	TRal	Cm
Qgm	Tvb	TRat	Co
Qga	Tvte	TRt	Ct
Qgr	Tm	TRtu	Zm
Qgy	Tm?	TRad	Zmf
Qgp	Tk	TRtl	Zbc
Qgmp	Tk?	TRtla	water
Qgap	Tkq	TRw	
Qgo	Tkt	Pp	

Base from USGS Provo 30' x 60' Quadrangle (1986)
Projection: UTM Zone 12
Datum: NAD 1927
Spheroid: Clarke 1886

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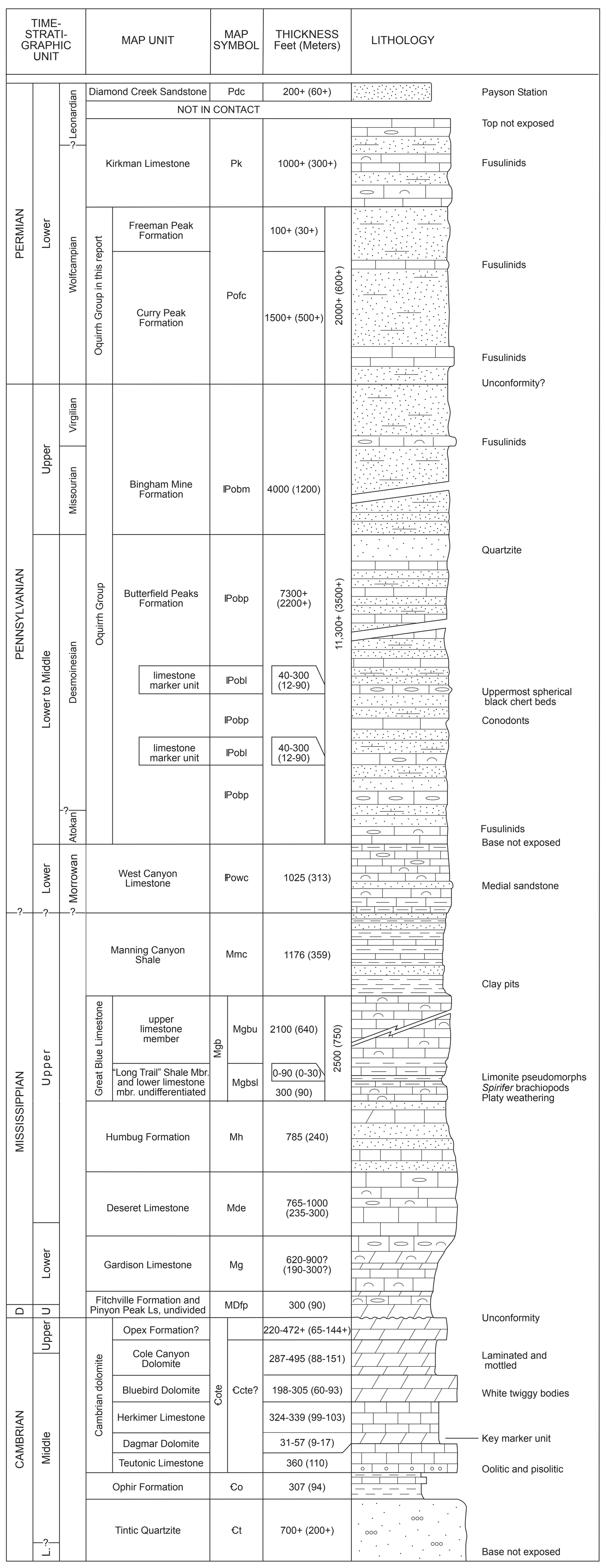
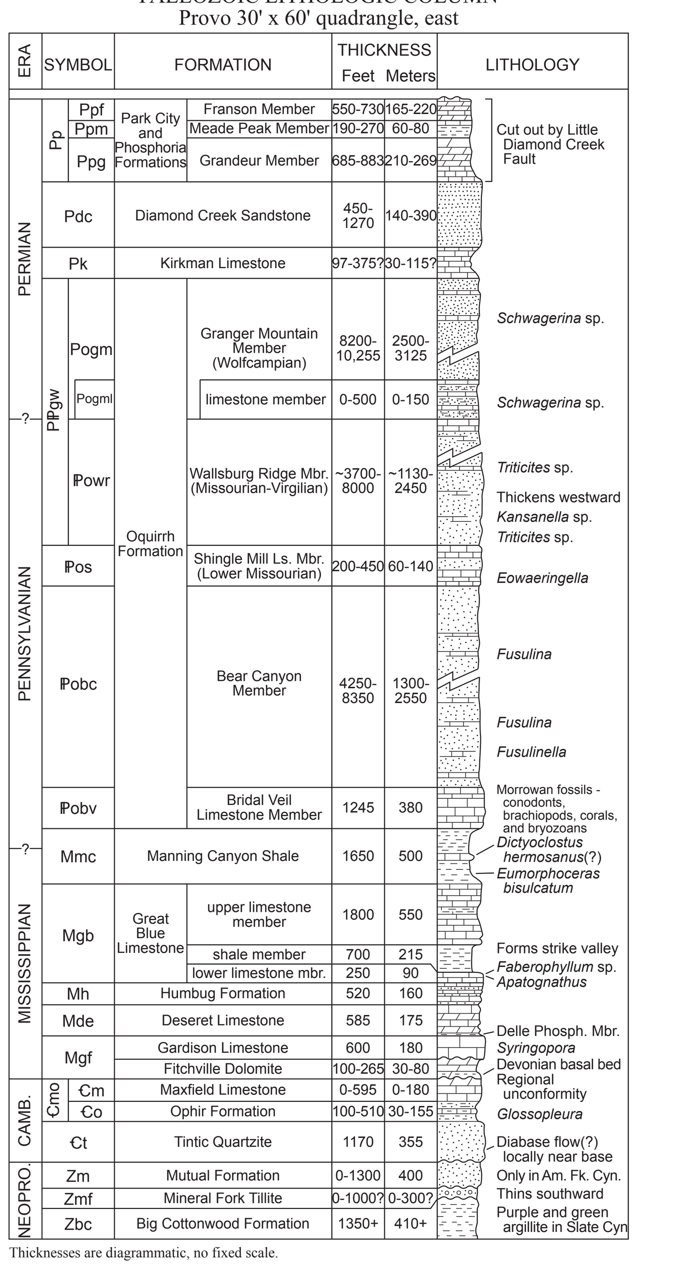
This interim geologic map is compiled from detailed new mapping of key 7.5' quadrangles, revised previously published 7.5' quadrangles, and new 1:24,000 to 1:50,000-scale reconnaissance geologic mapping, producing complete coverage at a scale of 1:62,500. This new map fills a gap in Utah's intermediate-scale geologic map coverage and is available as a paper map or GIS files. The Provo 30' x 60' quadrangle covers part of the populous Wasatch Front and Utah Valley, which have many different geologic hazard concerns, and the adjacent Wasatch Range, with competing recreational, forest, watershed, and geologic resource issues. Precambrian to Cretaceous sedimentary strata were deformed by Late Cretaceous to early Tertiary contractional folding and faulting of the Sevier orogeny, middle Tertiary regional extensional collapse or relaxation that was accompanied by igneous activity, and late Tertiary to Holocene basin-and-range extensional faulting. Much of the eastern part of the quadrangle is covered by Tertiary strata that were deposited after the Sevier orogeny and before and during middle Tertiary extension. The most prominent feature of the basin-and-range extensional faulting is the Provo segment of the Wasatch fault zone, which separates Utah Valley from the Wasatch Range. Utah Valley is filled with up to 4500 meters of basin fill that is mostly mantled by late Pleistocene Lake Bonneville deposits. Late Pleistocene glacial deposits are present at higher elevations in the Wasatch Range.

PALEOZOIC LITHOLOGIC COLUMN
Provo 30' x 60' quadrangle, west

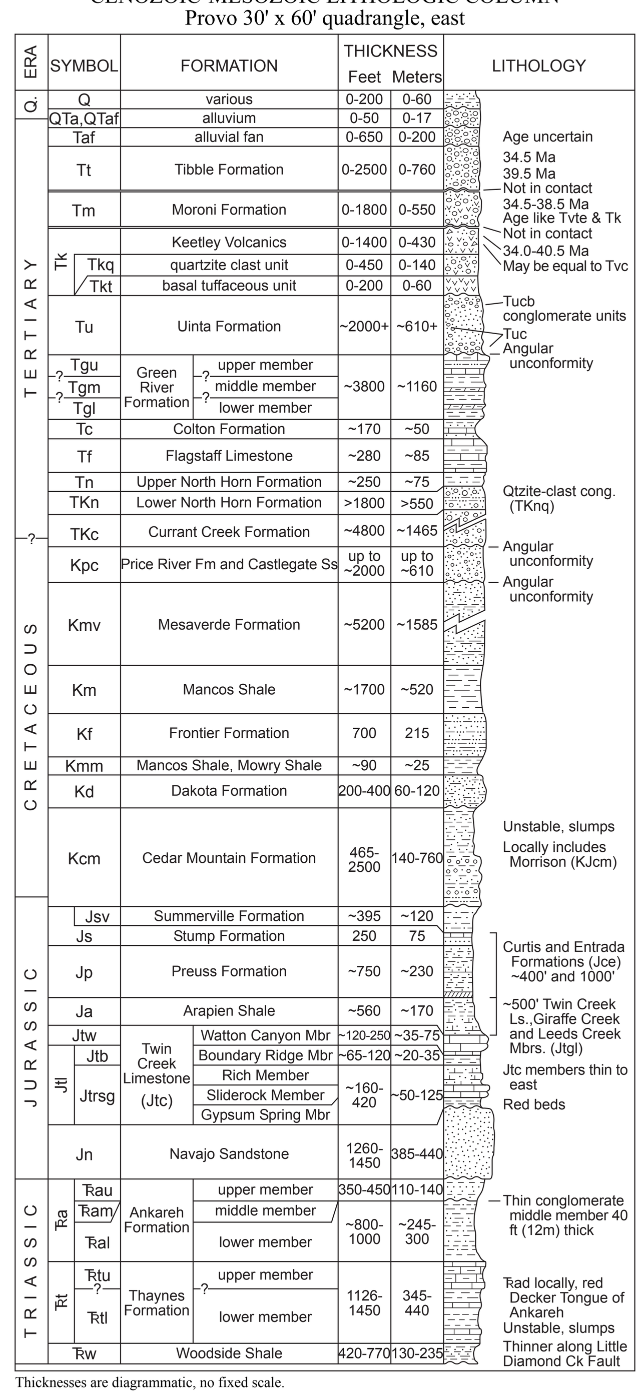


PALEOZOIC LITHOLOGIC COLUMN
Provo 30' x 60' quadrangle, east



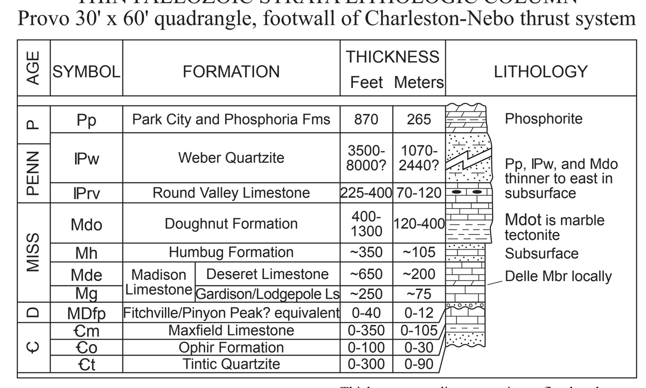
Thicknesses are diagrammatic, no fixed scale.

CENOZOIC-MESOZOIC LITHOLOGIC COLUMN
Provo 30' x 60' quadrangle, east



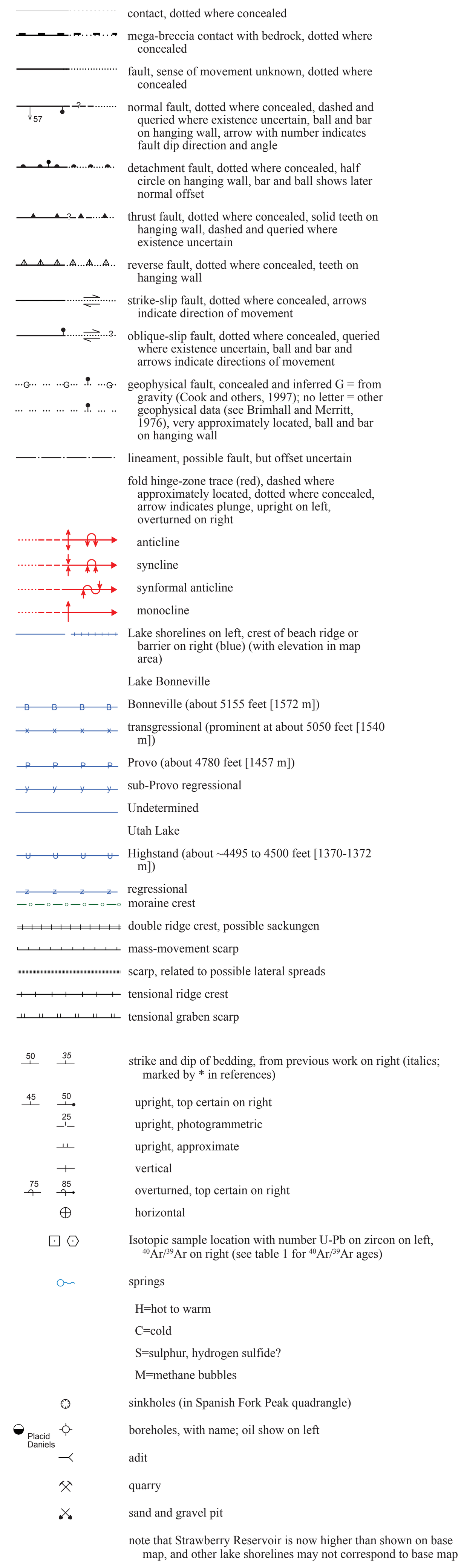
Thicknesses are diagrammatic, no fixed scale.

THIN PALEOZOIC STRATA LITHOLOGIC COLUMN
Provo 30' x 60' quadrangle, footwall of Charleston-Nebo thrust system



Thicknesses are diagrammatic, no fixed scale.

GEOLOGIC SYMBOLS



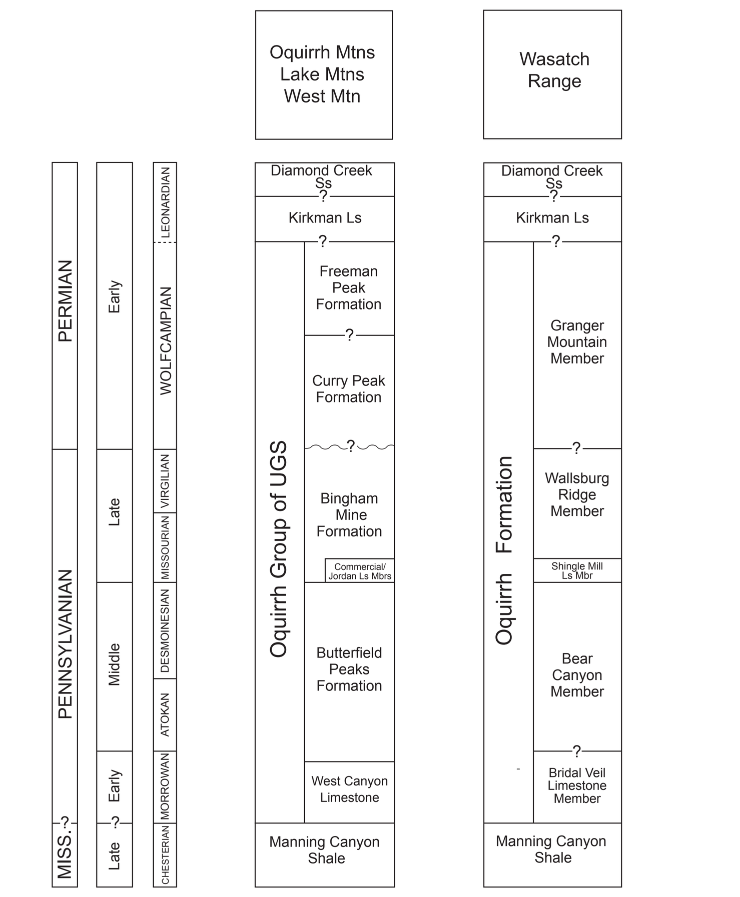
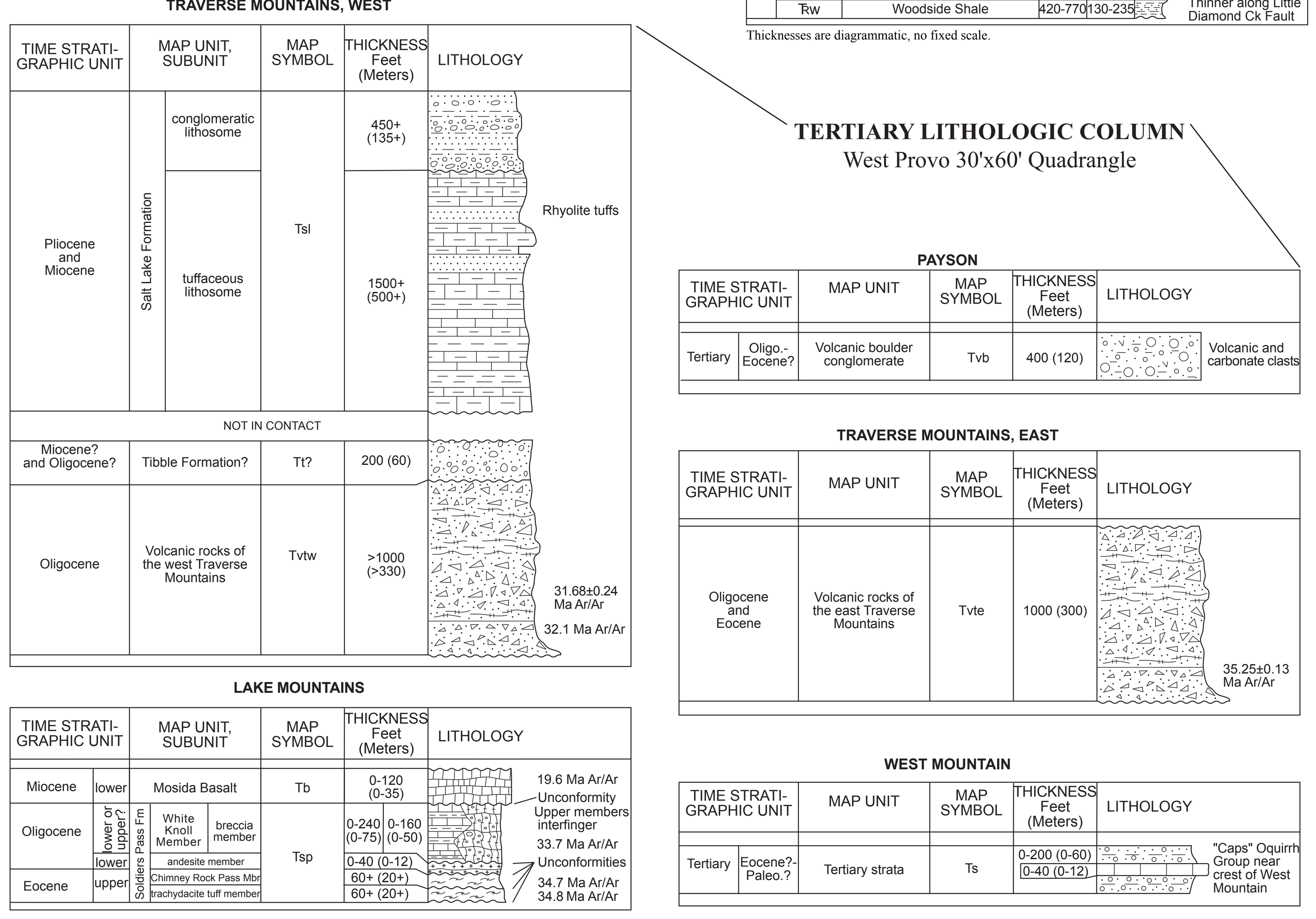
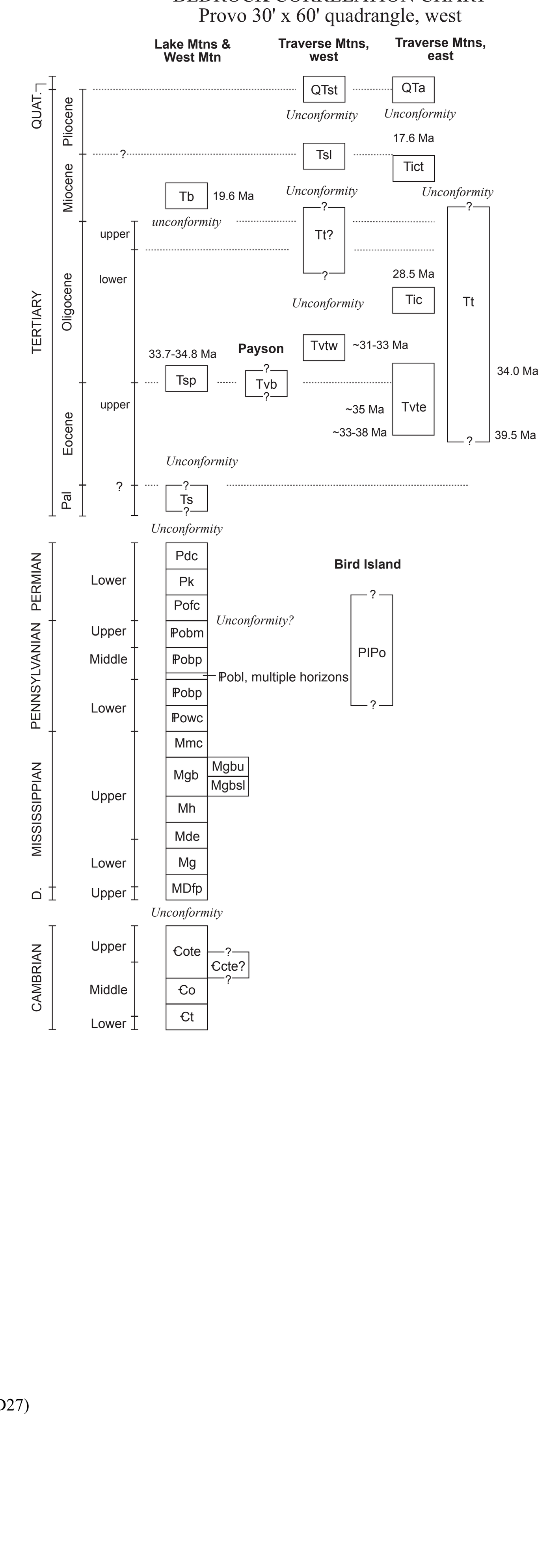


Figure 2. Comparison of stratigraphic nomenclature for the Oquirrh Formation/Group and associated strata near Salt Lake and Utah Valleys, north-central Utah. In the western part of the map the Utah Geological Survey (UGS) extends the Oquirrh Group to include the Curry Peak and Freeman Peak Formations.

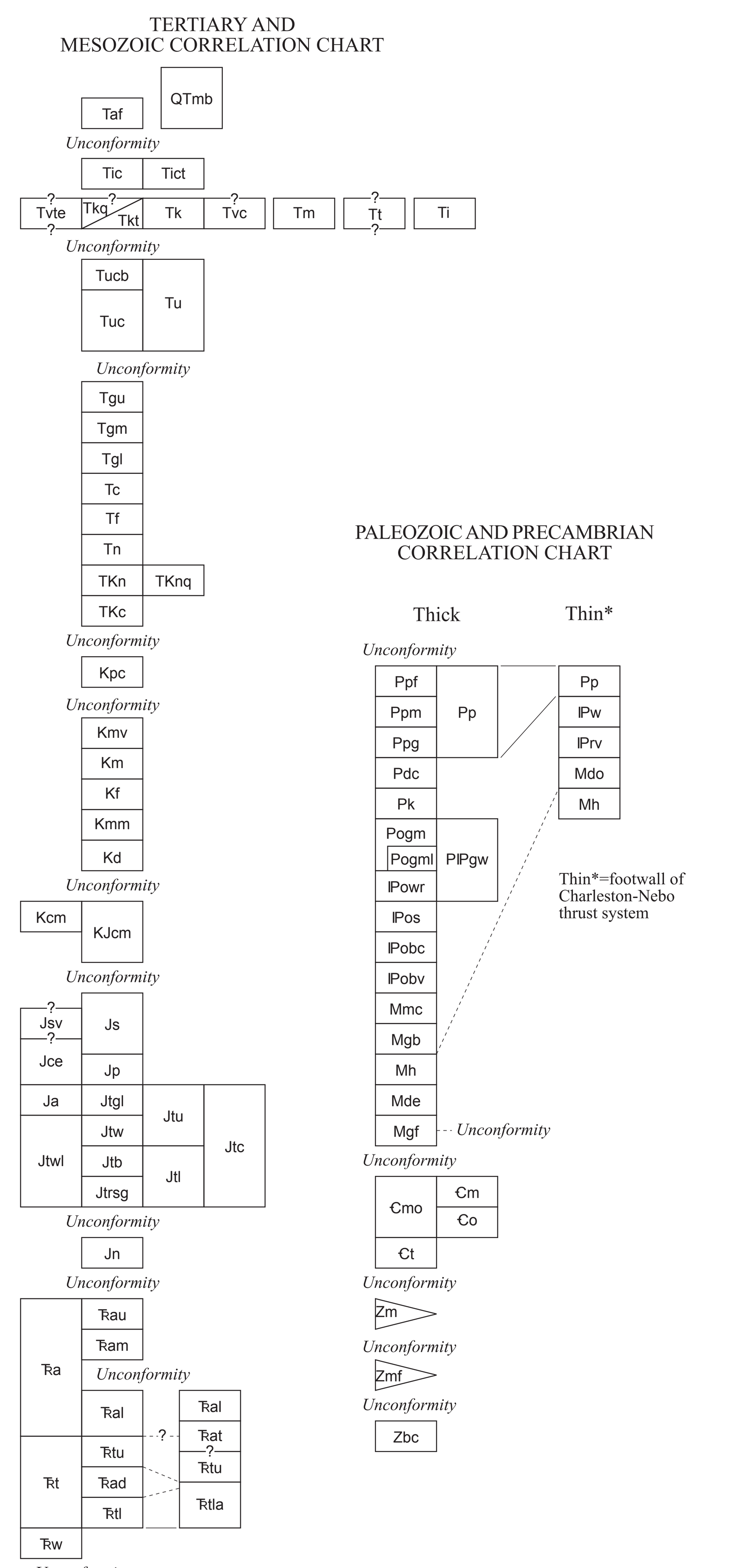
TERTIARY LITHOLOGIC COLUMN
West Provo 30'x60' Quadrangle



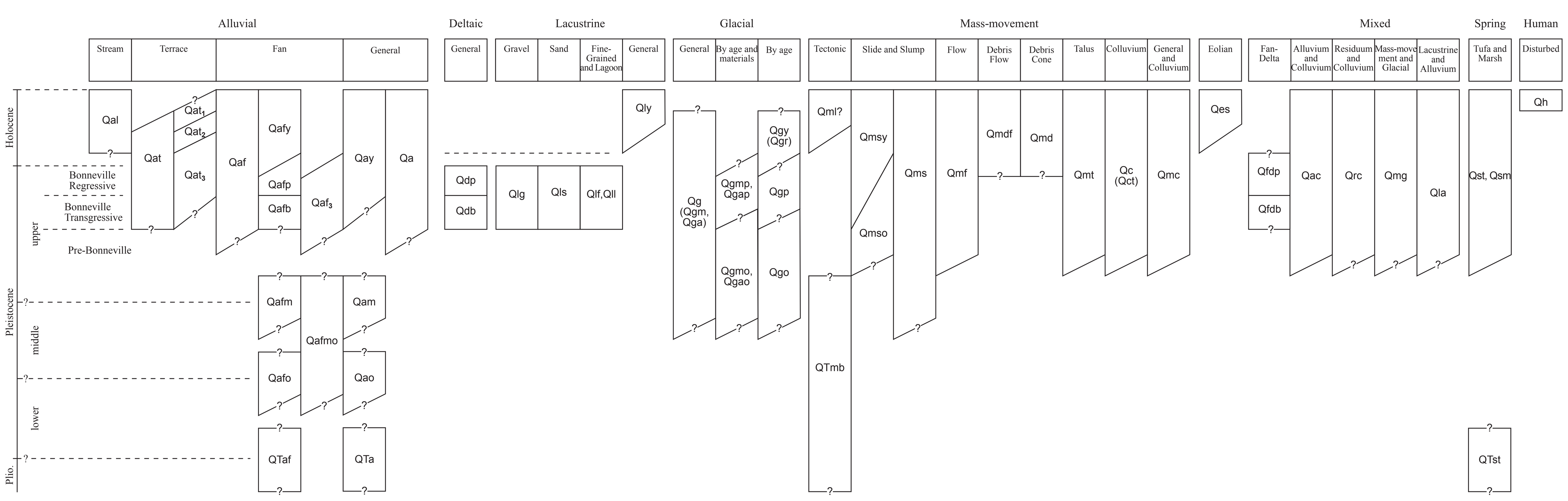
BEDROCK CORRELATION CHART
Provo 30' x 60' quadrangle, west



BEDROCK CORRELATION CHART
Provo 30' x 60' quadrangle, east



QUATERNARY CORRELATION CHART
Provo 30' x 60' quadrangle



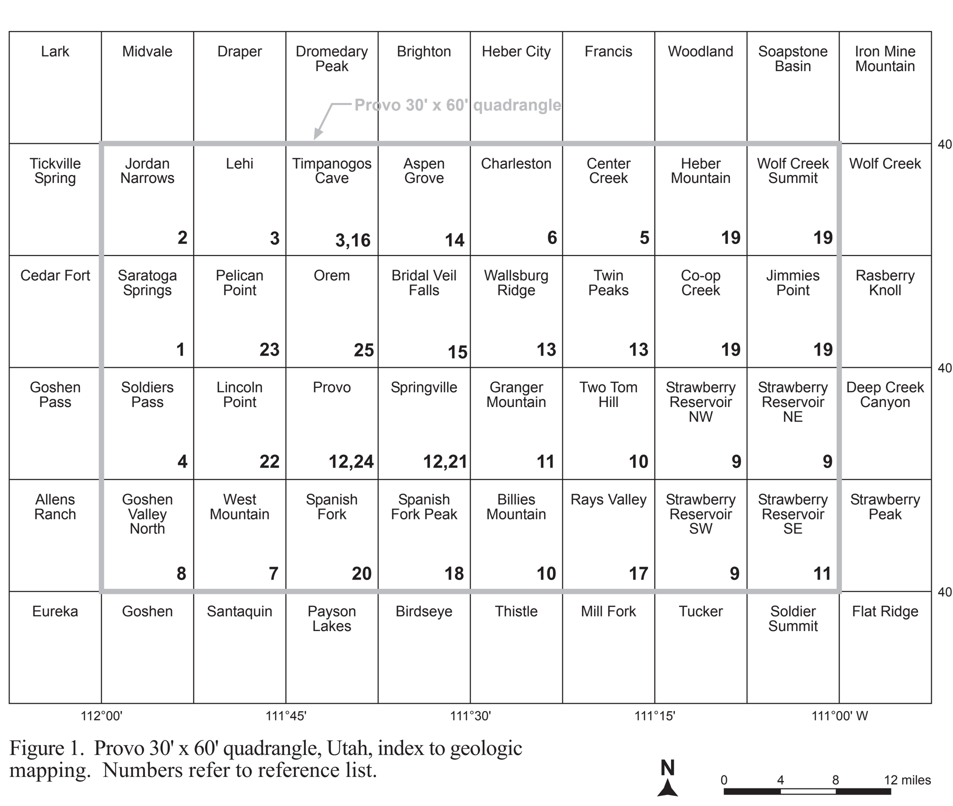


Figure 1. Provo 30' x 60' quadrangle, Utah, index to geologic mapping. Numbers refer to reference list.

TABLE 1. Summary of $^{40}Ar/^{39}Ar$-age analyses from the area of the Provo 30' x 60' quadrangle (modified from Deino and Keith, 1997; Constenius and others, 2003; Christiansen and others, 2007; and UGS and NMGRL, 2007). Latitude and longitude (in NAD27) corrected for samples in Provo 30' x 60' quadrangle and ages corrected/modified for analyses funded by STATEMAP.

Sample number	Unit	Latitude	Longitude	Age+2sd (Ma)	Mineral	Type of analysis
SP-3303	Mosida basalt	40° 10' 39.3"	111° 58' 25.0"	19.47±0.14	groundmass	furnace step-heating$
SP-4003	Mosida basalt	40° 09' 2.2"	111° 59' 22.4"	19.65±0.17	groundmass	furnace step-heating$
Tick 28*	Tvtw	40° 26' 28"	112° 05' 27"	32.12±0.14	plagioclase	single crystal Argon-ion step-heating
SP-3205	Tsp, breccia mbr	40° 09' 1.6"	111° 59' 38.3"	33.73±0.65	groundmass	furnace step-heating$
KNC7894-44*	Moroni	39° 56.867'	111° 30.983'	34.43±0.10	sanidine	single crystal CO_2 fusion
KNC101701-7*	Moroni	39° 51.377'	111° 25.807'	34.63±0.09	sanidine	single crystal CO_2 fusion
KNC71194-5	Moroni(?)	40° 07' 16.5"	111° 25' 37.4"	34.68±0.09	sanidine	single crystal CO_2 fusion$
KNC90299-1	intrusion	40° 19.056'	111° 19.657'	34.70±0.16	biotite	furnace step-heating$
SP-603A	Tsp, CRP tuff	40° 12' 12.2"	111° 58' 40.0"	34.70±0.07	sanidine	single crystal CO_2 fusion$
SP-1603B	Tsp, CRP tuff	40° 09' 18.7"	111° 58' 46.5"	34.70±0.07	sanidine	single crystal CO_2 fusion$
SP-1903	Tsp, basal tuff	40° 09' 22.7"	111° 58' 33.1"	34.79±0.10	biotite	furnace step-heating$
KNC101701-1	Moroni(?)	40° 04' 23.3"	111° 27' 21.4"	34.86±0.09	sanidine	single crystal CO_2 fusion$
L33103-9	Tvte	40° 28.010'	111° 50.419'	35.25±0.13	biotite	furnace step-heating$
KNC61093-2T	Tibble, lower	40° 28.982'	111° 38.422'	36.56±0.15	biotite	single crystal Argon-ion step-heating
KNC101701-4	Moroni(?)	40° 04' 02.3"	111° 26' 22.7"	37.18±0.38	biotite	single crystal CO_2 fusion$
KNC92799-6	Keetley, "base"	40° 22' 17.8"	111° 10' 19.8"	37.25±0.14	hornblende	furnace step-heating$
KNC92899-2	Tvc	40° 15' 44.5"	111° 12' 23.2"	37.73±0.28	biotite	furnace step-heating$
KNC6901-1*	Keetley	40° 44.483'	111° 20.857'	38.20±0.11	sanidine	single crystal CO_2 fusion
KNC92799-5	Keetley	40° 22' 21.9"	111° 10' 19.3"	40.45±0.18	hornblende	furnace step-heating$

*=sample not from Provo 30' x 60' quadrangle map.

Tvtw=Volcanic rocks of west Traverse Mountains
Tsp=Soldiers Pass Formation
Tvte=Volcanic rocks of east Traverse Mountains
CRP=Chimney Rock Pass Tuff Member
Tvc=Volcaniclastic rocks of Strawberry Valley

All analyses performed at the New Mexico Geochronology Research Laboratory, Socorro, New Mexico, except Argon-ion step heating analyses which were done at the University of California, Berkeley Geochronology Center (Tick 2) and the University of Alaska, Fairbanks (two samples).
$ Indicates analysis paid for by STATEMAP funding.

TABLE 2. Summary of zircon U-Pb age analyses from the area of the Provo 30' x 60' quadrangle. Zircon mineral separates were analyzed using laser-ablation and inductively coupled plasma mass spectrometry (LA-ICPMS). Latitude and longitude in NAD27.

Sample number	Unit	Latitude	Longitude	Age+2sd (Ma)	No. of analyses	Comments
KNC62695-2*	Tic	40° 31.400'	111° 41.017'	30.5 ± 0.6	8	granite-granodiorite
KNC053107-3[$]	Tt	40° 14.665'	111° 29.311'	33.7 ± 0.6	13	tuff
KNC060407-14[$]	Tvte	40° 29.319'	111° 39.725'	35.7 ± 0.6	21	latite lava
KNC61093-2T	Tt	40° 28.982'	111° 38.422'	36.1 ± 1.7	33	tuff
KNC070109-1[$]	Tubc	40° 23.240'	111° 00.908'	38.9 ± 0.8	20	tuff
KNC070109-2[$]	Tubc	40° 23.245'	111° 01.005'	39.6 ± 0.7	29	tuff
JC 99-37[$]	TRat	40° 21.017'	111° 12.400'	249.0 ± 3.0	34	tuff

*=sample not from Provo 30' x 60' quadrangle map; result from Constenius (1998).
[$]=analysis paid for by STATEMAP funding.

Tic=Little Cottonwood stock
Tt=Tibble Formation
Tvte=Volcanic rocks of east Traverse Mountains
Tubc=Uinta Formation, boulder conglomerate
TRat=Ankareh and Thaynes Formations, transitional unit

All analyses performed at the Arizona LaserChron Center, Department of Geosciences, University of Arizona, Tucson, Arizona.

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Disclaimer

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Map Unit Descriptions

All years noted in Quaternary units (Q_) are Carbon-14 years unless otherwise noted.

Qh **Human disturbance** (Historical) - Material used in and near the Deer Creek, Strawberry, and Currant Creek dams; fill along U.S. Interstate highway 15, U.S. Highway 189 in Provo Canyon, and U.S. Highway 6 in Spanish Fork Canyon; fill at the former Geneva Steel plant (near the town of Vineyard) and slag heap south of Provo; larger sand and gravel pits; several sewage lagoons and landfills; debris basins at the mouths of numerous Canyons; Keigley Quarry waste rock and fill that obscures the underlying geology of southern West Mountain; only the largest deposits are mapped. Faults in unit shown as exposed (solid) where scarps are not entirely obscured.

Qa **Alluvium, undivided** (Quaternary) - Sand, silt, clay, and gravel in stream and alluvial-fan deposits; composition depends on source area; in Spanish Fork Canyon mapped alluvium is pre-latest Pleistocene Lake Bonneville, lip of upper surface at least 120 feet (40 m) above active stream, and 0 to 20 feet (0-6 m) thick; in Bridal Veil Falls quadrangle the alluvium is about 160 feet (50 m) above active stream, about 160 feet (50 m) thick, and is about the same age as latest Pleistocene (Pinedale age) glacial outwash (Qgap). Also on broad surfaces on top of Cretaceous bedrock, 0 to 240 feet (0-75 m) above tributaries to Currant Creek, upstream from Currant Creek Reservoir; may be partly glacial outwash; 0 to 50 feet (0-15 m) thick.

Qay **Younger alluvium** (Holocene and upper Pleistocene) - Mapped in Utah Valley as undivided post-Provo shoreline (younger) alluvial fan (Qafy) and terrace (Qat2) alluvium; likely less than 50 feet (15 m) thick. In Heber Valley, moderately sorted sand, silt, and gravel forming a broad planar surface; age constrained by local veneer of loess or alluvium, and stage II (Birkeland and others, 1991) soil carbonate development; in part deposited as glacial outwash in braided streams and therefore mostly late Pleistocene in age; borehole data indicate up to about 450 feet (140 m) thickness of fill in Heber Valley (Qay+Qao), and thicknesses about 100 feet (30 m) less than estimate from gravity data for same locations (see Peterson, 1970).

Qam **Middle alluvium** (upper Pleistocene) - Variably sorted, unconsolidated silt, sand, and gravel deposited by streams and in alluvial fans; mapped on sloping benches 120 to 240 feet (35-70 m) above active drainages in Wallsburg Ridge, Two Tom Hill, and Granger Mountain quadrangles, thinner and 160 to 300 feet (50-90 m) above active drainages in Aspen Grove quadrangle; estimated thickness 20 to 80 feet (5-25 m).

Qao **Older alluvium** (middle and lower Pleistocene) - Moderately sorted, unconsolidated sand and silt with lenses of pebbles and cobbles; clasts are subrounded to rounded Oquirrh Formation and minor intermediate volcanic rock, likely Keetley Volcanics;

mapped about 300 feet (90 m) above Provo River (now obscured by Deer Creek Reservoir) in what is likely a paleo-meander (QTa of Biek and others, 2003); 0 to about 30 feet (0-9 m) thick; Sullivan and others (1988) suggested these deposits are older than 730 ka; similar small exposure in Daniels Canyon, Center Creek quadrangle, is 300 to 400 feet (90-120 m) above drainage.

Qal **Stream and floodplain alluvium** (Holocene) - Sand, silt, clay, and gravel in channels and floodplains; composition depends on source area; 0 to 20 feet (0-6 m) thick. Locally underlain by and interbedded with spring tufa in western Heber Valley.

Qat, Qat1, Qat2, Qat3, Qaty

Stream-terrace alluvium (Holocene and upper Pleistocene) - Sand, silt, clay, and gravel in terraces above floodplains; Qat where undivided; number suffixes apply to local drainages with multiple terrace levels with lowest (youngest) terraces labeled 2; Qat2 surfaces typically 10 to 35 feet (3-11 m) above adjacent drainage while Qat3 surfaces typically 35 to 60 or more feet (11-18+ m) above adjacent drainage; 0 to 45 feet (0-14 m) thick. In the Springville and Spanish Fork Peak quadrangles, Qat1 are 5 to 15 feet (1.5-5 m) above modern streams, Qat2 are 30 to 40 feet (9-12 m) above, and Qat3 are 40 to 50 feet (12-15 m) above and postdate the regressive Lake Bonneville fan-deltas (Qfdp); Qaty used where terrace level indeterminate or where terraces of different levels are too small to show separately at map scale; however, partly glacial outwash in Center Creek quadrangle.

Qaf **Alluvial-fan deposits, undivided** (Holocene and upper[?] Pleistocene) - Mostly sand, silt, and gravel that is poorly stratified and poorly sorted; typically deposited at drainage mouths; used where age(s) of fans uncertain; generally less than 40 feet (12 m) thick.

Qafy **Younger alluvial-fan deposits** (Holocene and upper Pleistocene) - Mostly sand, silt, and gravel that is poorly stratified and poorly sorted; deposited at drainage mouths; Qafy fans are mostly Holocene and cover Lake Bonneville deposits or deflect stream channels; generally less than 40 feet (12 m) thick.

Qaf3 **Lake Bonneville-age alluvial fan deposits** (upper Pleistocene) - Deposits similar to Qafy but incised by active drainages and Qafy fans are inset into Qaf3 fans; includes fans related to Bonneville and transgressive shorelines (Qafb), as well as Provo and regressive shoreline (Qafp); generally less than 40 feet (12 m) thick.

Qafp **Regressive (Provo) Lake Bonneville-age alluvial fan deposits** (upper Pleistocene) - Deposits similar to Qafy but incised by active drainages and extend below the Provo shoreline; exposed thickness less than 30 feet (10 m) in the Springville quadrangle.

Qafb **Transgressive (Bonneville) Lake Bonneville-age alluvial fan deposits** (upper Pleistocene) - Deposits similar to Qafy but incised by active drainages and typically above and extending to the Bonneville shoreline; always above the Provo shoreline; so can be separated from deposits related to the regressive phase of the lake; exposed thickness less than 15 feet (5 m) in the Springville quadrangle.

Qafm **Intermediate-level alluvial-fan deposits** (upper and middle Pleistocene) - Fan remnants found along mountains near Utah Lake and in Round Valley; deposits similar to Qafy, but incised by active drainages and characterized by carbonate-bearing soil horizons (stage II to III of Birkeland and others, 1991); Qafm probably grades laterally in Utah Valley subsurface into lacustrine sediment of the Little Valley lake cycle; based on drainage incision and soil carbonate development, likely correlative to unit Qaf4 of Solomon and Machette (2008); 0 to about 50 feet (0-15 m) thick.

Qafmo **Intermediate and older alluvial-fan deposits, undivided** (Pleistocene) - Fan remnants like Qafm and Qafo around Utah Lake; mapped where fans are poorly exposed or lack characteristic geomorphic expression of Qafm below adjacent Qafo; also shown where fan remnants are too small to show separately at map scale; correlative with Qafo of Machette (1992). In Charleston quadrangle, Qafmo similar to Qafm and Qafo, but development of soil carbonate horizon (stage III of Birkeland and others, 1991) and amount of drainage incision intermediate between Qafm (stage II to III) and Qafo (stage III+ to IV); Qafmo=Qaf3 of Biek and Lowe (2005); 0 to about 50 feet (0-15 m) thick.

Qafo **Older alluvial-fan deposits** (middle and lower Pleistocene) - Poorly sorted, pebble to cobble gravel, locally bouldery, in a matrix of sand, silt, and clay; present in deeply dissected fan remnants; where mapped along the Wasatch mountain front, only stage II-III soil carbonate development and mostly truncated by Bonneville shoreline of Lake Bonneville; correlative with Qaf5 of Solomon and Machette (2008); thickness probably less than 60 feet (20 m). Machette (1992) reported that his Qaf5 exposed in the Payson Lakes quadrangle contains the Lava Creek B volcanic ash bed (Izett and Wilcox, 1982, Utah locality 9) $^{40}Ar/^{39}Ar$ dated at ~ 640 ka (Lanphere and others, 2002), so is pre-Little Valley lake cycle; probably grade laterally in Utah Valley subsurface into lacustrine sediment of the Pokes Point and older lake cycles (Scott and others, 1983; Machette and Scott, 1988). Qafo in Center Creek quadrangle is 200 feet (60 m) above active drainages, and is up to 240 feet (75 m) above Diamond Fork Creek; Qafo in Charleston quadrangle is not so deeply incised but has stage III+ to IV soil carbonate development.

Qac **Alluvium and colluvium** (Quaternary) - Includes clay- to boulder-size sediment of stream and fan alluvium, colluvium, and, locally, mass-movement deposits; 0 to 20 feet (0-6 m) thick.

Qc **Colluvium** (Quaternary) - Includes slopewash and soil creep; composition depends on local bedrock; generally less than 20 feet (6 m) thick.

Qct **Colluvium and talus, undivided** (Quaternary) - Very poorly sorted angular to subangular debris at the base of and on steep, variably vegetated slopes; sediments include cobbles and boulders and finer-grained interstitial material; deposited principally by rock fall; prominent in cirques in the Wasatch Range, extending downslope to cover glacial deposits; estimate 0-30 feet (0-9 m) thick.

Qmc **Mass-movement and colluvial deposits, undivided** (Quaternary) - Includes landslides and areas of slope wash and soil creep, and locally talus; mapped in areas of subdued morphology and where mass-movement and colluvial deposits cannot be shown separately at map scale; composition depends on local sources; 0 to 40 feet (12 m) thick.

Qmt **Talus deposits** (Holocene and Pleistocene) - Angular debris on and at the base of steep, mostly unvegetated slopes; typically composed of Oquirrh Formation quartzite and form talus cones in Orem quadrangle; in Wasatch Range, locally includes protalus ramparts too small to show separately at map scale; 0 to 30 feet (0-9 m) thick.

Qmd **Debris-cone deposits** (Holocene and Pleistocene) - Mostly angular and coarse debris in cones at the base of steep drainages in Wasatch Range; seems to be mixture of talus and debris flow deposits with some slope wash and creep material; typically composed of Oquirrh Formation fragments; locally likely includes glacial outwash; 0 to 40 feet (0-12 m) thick.

Qmf **Flow deposits** (Quaternary) - Exhibit hummocky internal morphology and distinct hummocky margins; mostly large-scale earthflows in Wasatch Range (on Great Blue Limestone, Manning Canyon Shale, and Tertiary strata) and near Currant Creek (on clay-rich Mesozoic and Tertiary strata); near Provo Canyon deposits grade into mega-breccia (QTmb) of nearly intact bedrock; as much as 200 feet (60 m) thick near Currant Creek and at least that thick near Provo Canyon.

Qmdf **Debris flow deposits** (Holocene and Pleistocene) - Typically poorly sorted with angular to subangular pebbles to boulders in a muddy to sandy matrix; present in fan- to belt-shaped aprons with numerous overlapping levees and channels and originates in Oquirrh Formation; mapped separately from Qmf, Qmd, Qms, and Qaf because distinct levees and channels are visible; estimate 60 feet (18 m) thick.

Qms, Qmsy, Qmso

Landslides (Quaternary) - Poorly sorted clay- to boulder-sized material; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced bedrock; includes slump and flow deposits; morphology becomes subdued with age; divided into younger (Holocene) and older deposits where possible (suffixes y and o, respectively); bedrock units most susceptible to mass movements include the Tertiary Moroni Formation (Tm), Keetley Volcanics (Tk, Tkt), volcaniclastic rocks of Strawberry

Valley (Tvc), Uinta Formation (Tu and Tucg), Currant Creek Formation (TKc), clay-rich Mesozoic rocks (Kmv, TRa), Manning Canyon Shale (Mmc), and shaly strata in the Great Blue Limestone (Mgb); glacial deposits (various Qg units) are also highly susceptible; thicknesses highly variable. Large blocks of bedrock in landslides are mapped separately with the bedrock unit in parentheses in the label - Qms(rock unit); Qms queried where block may be in-place bedrock.

Qml? **Lateral-spread deposits?** (Holocene to upper Pleistocene) - Pebbly sand, sand, silt, and clay below (post-dating) the Provo shoreline, typically with scarps mapped; thickness probably less than 50 feet (15 m). Lateral spreads occur during earthquake ground shaking. Mapped and queried by Miller (1982) in Utah Valley, and named the Beer Creek and Springville/Spanish Fork features by Harty and Lowe (2003); both features were mapped by Machette (1992), who removed the query, although Harty and Lowe (2003) were unsure of their origin.

Qmg **Mass-movement and glacial deposits, undivided** (Holocene and upper Pleistocene) - Glacial deposits (see unit Qg description) in displaced landslide masses in northeast part of map area and in Wasatch Range; includes displaced bedrock in the lobate mass on the north side of Lake Creek drainage, Heber Mountain quadrangle; landslide masses originated in and above glacial deposits; locally includes small wet depressions in which younger sediment has accumulated; up to 300 feet (90 m) thick.

Qg, Qgm, Qga

Glacial deposits, undivided (Holocene and upper and middle Pleistocene) - Includes till (moraine deposits) and outwash of various ages, but mostly Pinedale age; till is non-stratified, poorly sorted clay, silt, sand, cobbles, and boulders and is mapped as Qgm (moraines) where distinct shapes of end, recessional, and lateral moraines are visible; outwash (Qga) is stratified and variably sorted, but better sorted and bedded than till due to alluvial reworking; Qga mapped directly downslope from other glacial deposits where thick enough to obscure older deposits and bedrock, and where it can be separated from ground moraine (mapped as Qg) and alluvium (various Qa); all glacial deposits locally include mass-movement deposits (Qms, Qmt, Qct) and rock glaciers (Qgr) too small to show at map scale; estimate 0-150 feet (0-45 m) thick. Queried where glacial origin uncertain due to low elevation, such as on west slope of Mount Timpanogos.

Qgr **Rock glacier deposits** (upper? Pleistocene) - Angular, mostly cobble- to boulder-sized debris with little matrix in unvegetated mounds with lobate crests; present in cirques in Wasatch Range; locally includes protalus ramparts; inactive (no ice matrix); may be same age as younger glacial deposits (Qgy), youngest deposits seem to be where snowfield is shown by Baker and Crittenden (1961); likely 0 to 30 feet (0-9 m) thick.

Qgy **Younger glacial deposits** (Holocene and uppermost Pleistocene) - Non-stratified, poorly sorted clay, silt, sand, cobbles, and boulders in cirque basins; clasts are angular and derived from headwall bedrock sources; generally characterized by sharp, mostly non-vegetated moraines and very poor soil development; likely includes lower and possibly middle Holocene deposits (see Madsen and Currey, 1979); includes unmapped arcuate ridge in talus that might be Little Ice Age end moraine in Cascade Cirque (formerly Big Provo Hole cirque); 0 to 50 feet (0-15 m) thick.

Qgp, Qgmp, Qgap

Glacial deposits, Pinedale age (upper Pleistocene) - Mapped as undivided deposits (Qgp), till in distinct vegetated moraines (Qgmp), and alluvially reworked outwash (Qgap); see differences under unit Qg; till has weak soil development and mapped moraines show moderate to sharp morphology; up slope includes mostly vegetated recessional deposits from glacial stillstands and/or minor advances (deglacial pauses) (see Madsen and Currey, 1979); locally include small wet depressions in which younger sediment has accumulated; 0 to 150 feet (0-46 m) thick.

Qgo, Qgmo, Qgao

Older glacial deposits (upper and middle? Pleistocene) - Mapped down drainage from and locally laterally above Pinedale deposits; shown as undivided deposits (Qgo), till in distinct vegetated moraines (Qgmo), and alluvially reworked outwash (Qgao); see differences under unit Qg; till has well-developed soil and mapped moraines have subdued morphology; age uncertain, may be older Pinedale deposits (see Madsen and Currey, 1979) or could be Bull Lake equivalent in age (~Little Valley Lake cycle) (Scott and others, 1983; Phillips and others, 1997); 0 to 150 feet (0-45 m) thick (see Biek, 2005b).

Qfdp **Lake Bonneville alluvial-fan and delta deposits, related to regression** (uppermost Pleistocene) - Cobbly gravel, sand, silt, and clay deposited above (subaerial) and in Lake Bonneville (subaqueous); typically mapped where Provo shoreline is obscure, so that line cannot be drawn between fan and delta; typically better sorted delta and lake deposits under poorly sorted regressive alluvial-fan deposits; mapped at the mouth of Dry Canyon and best developed at the mouths of Spanish Fork, Provo, and American Fork Canyons; at least 150 feet (45 m) thick.

Qdp **Deltaic deposits near and below Provo shoreline** (uppermost Pleistocene) - Moderately to well-sorted gravel in a matrix of sand and silt; interbedded with thin pebbly sand beds; clasts subrounded to rounded; includes regressional deltas more than a mile down slope from the Provo shoreline; deposited as foreset beds having original dips of 30 to 35 degrees and bottomset beds having original dips of 1 to 5 degrees; commonly capped by an unmapped thin veneer of topset alluvial deposits or by mapped fan-delta deposits (Qfdp) related to regressional (y) shorelines; best exposed in terrace scarps; shown by

Biek (2005b) as Qldp (foreset beds) and Qlap (topset beds); up to 150 feet (45 m) exposed thickness.

Qfdb **Lake Bonneville alluvial-fan and delta deposits, related to transgression** (uppermost Pleistocene) - Cobbly gravel, sand, silt, and clay deposited above (subaerial) and in Lake Bonneville (subaqueous); typically mapped where Bonneville shoreline is obscure, so that line cannot be drawn between fan and delta; typically better sorted delta and lake deposits over poorly sorted transgressive alluvial-fan deposits; mapped at the mouth of Dry Canyon and up Spanish Fork Canyon; at least 150 feet (45 m) thick.

Qdb **Deltaic deposits near Bonneville shoreline** (uppermost Pleistocene) - Mostly rounded gravel and sand deposited in delta at the mouth of American Fork Canyon at and below the Bonneville shoreline of uppermost Pleistocene Lake Bonneville; shown as Qlgb and Qldb by Biek (2005b); also mapped at the mouth of Dry Creek Canyon; up to 150 feet (45 m) exposed thickness.

Qlg **Lacustrine gravel and sand deposits** (uppermost Pleistocene) - Rounded gravel and sand deposited in beaches, typically near and above the Provo shoreline and at and below the Bonneville shoreline of Lake Bonneville; grades into unit Qls; estimate 40 feet (12 m) thick.

Qls **Lacustrine sand deposits** (upper Pleistocene) - Sand and some silt and gravel deposited in beaches, typically in two settings that correspond to transgressive and regressive phases of Lake Bonneville: (1) deposited below the Provo shoreline while the lake was at and regressing from (below) this shoreline, possibly as parts of deltas from several canyons, grading downslope into Qlf; and (2) deposited between the Provo and Bonneville shorelines of Lake Bonneville as the lake transgressed to and was at the Bonneville shoreline; estimate up to 200 feet (60 m) thick in Orem quadrangle. Locally includes Holocene eolian deposits that cannot be mapped separately because they grade imperceptibly into sandy lacustrine deposits (Qls) that are reworked by wind, in particular near the former Geneva Steel plant; thickness less than 10 feet (3 m).

Qlf **Fine-grained lacustrine deposits** (upper Pleistocene) - Silt and clay with some fine-grained sand; weathers to unstratified appearance but typically laminated; grades upslope into sandier and gravelly lacustrine and deltaic deposits; above the Provo shoreline, age is that of transgression and Bonneville shoreline; below Provo shoreline and slightly younger shorelines, age likely that of Lake Bonneville regression; likely less than 40 feet (12 m) thick.

Qll **Lagoon-fill deposits** (upper Pleistocene) - Silt and clay, with minor fine sand and pebbles; occupy level ground or closed depressions behind Lake Bonneville bars and barrier beaches; at least locally includes wind-blown and alluvial veneer; maximum thickness about 10 feet (3 m).

Qly **Young lacustrine deposits** (Holocene to upper Pleistocene?) - Silt, clay, and sand deposited along the margin of Utah Lake; mapped near and below the Utah Lake highstand elevation; forms sandy and locally pebbly beach and berm deposits at and below the Utah Lake high stand; between berms locally organic rich because unit includes small areas of spring and marsh deposits and mixed lacustrine and alluvial deposits; overlies sediments of the Bonneville lake cycle; thickness 0 to 20 feet (0-6 m). Brimhall and others (1975) reported that Holocene gray clayey silt composed mostly of calcite forms the upper 15 to 30 feet (5-10 m) of the sediments in Utah Lake. Qly includes white to light-gray, calcareous tufa that is spongy to dense and can contain mollusk shells; typically less than 1 foot (0.3 m) thick; tufa was reported on Rock (Bird) Island and below the Utah Lake highstand near Lincoln Point by Bissell (1963).

Qla **Lacustrine and alluvial deposits, undivided** (Holocene and upper Pleistocene) - Sand, silt, and clay in areas of mixed alluvial and lacustrine deposits that are undifferentiated because the units change imperceptibly into one another; likely stream and fan alluvium deposited during transgression of Lake Bonneville, overlain by thin Lake Bonneville deposits with post-Bonneville alluvium reworked from and on some lacustrine deposits; thickness typically less than 10 feet (3 m), but may be up to 40 feet (12 m) thick along the Jordan River.

Qes **Eolian sand** (Holocene and uppermost Pleistocene) - Moderately to well sorted, very fine to medium sand, with minor silt and clay; calcareous, loose to moderately firm where cemented by secondary calcium carbonate; forms thin sheets and small dunes in Utah and Goshen Valleys; typically derived from Lake Bonneville beach sand (Qls); dunes are from 3 to 10 feet (1-3 m) tall and sheets are 3 to 5 feet (1-1.5 m) thick.

Qst **Spring tufa deposits** (Holocene and Pleistocene) - Largely concealed by and interfingering with Heber Valley fill, so mapped as Qa/Qst (Qst typically exposed only at major springs); tufa is highly porous, pale yellowish gray, tan weathering calcium carbonate; present as beds in valley fill to depths greater than 150 feet (45 m) (Biek and Lowe, 2005). Also mapped along Wasatch fault zone in Timpanogos Cave quadrangle where it is calcareous tufa of uncertain origin, might be spring or Lake Bonneville tufa; thickness uncertain.

Qsm **Spring and marsh deposits** (Holocene to upper Pleistocene?) - Fine, organic-rich sediment associated with springs, ponds, seeps, and wetlands in Utah and Goshen Valleys; commonly wet, but seasonally dry; may locally contain peat deposits as thick as 3 feet (1 m); includes areas of mixed marsh and fine-grained Lake Bonneville deposits

(Qlf); overlies and grades into unit Qlf; present where water table is high; thickness commonly less than 10 feet (3 m).

Qrc **Residuum and colluvium** (Quaternary) - Poorly sorted clay- to boulder- sized, locally derived material; typically mapped on north-facing, vegetated slopes where bedrock and contacts are concealed; 0 to about 15 feet (0-5 m) thick. Only mapped in Center Creek and Twin Peaks quadrangles.

QTst **Spring deposits** (Pleistocene and Pliocene?) - White calcareous tufa and travertine in laminated, typically very thick beds; present just below Bonneville shoreline near Jordan Narrows and partly covered by lacustrine sand and gravel deposits (Qlg); as much as 30 feet (0-10 m) thick.

QTa **High-level alluvium** (lower Pleistocene and/or Pliocene?) - Clay- to boulder-size, locally derived material on gently sloping surfaces 300 to 600 feet (90-180 m) above adjacent drainages in Wallsburg Ridge, Center Creek, and Lehi quadrangles; may be younger than QTaf; estimate 0 to 50 feet (0-15 m) thick, but appears more than 200 feet (60 m) thick in Lehi quadrangle.

QTaf **High-level alluvial fans** (lower Pleistocene and Pliocene?) - Poorly sorted, clay- to boulder-size, locally derived material in gently sloping fan remnants as low as 450 feet (140 m) above and up to 800 to 1500 feet (245-460 m) above Daniels Canyon, Center Creek quadrangle (Biek and others, 2003); 0 to 50 feet (0-15 m) thick. Near Cummings Flat, mixed-clast (Oquirrh Formation & volcanic rocks) deposits reflect nearby Keetley Volcanic rocks (Tk).

QTmb **Megabreccia** (Pleistocene and Pliocene?) - Mostly formed during displacement on underlying Manning Canyon Shale near the mouth of Provo Canyon and in the upper reaches of Provo Canyon at the south end of North Fork Ridge; ranges from nearly intact brecciated bedrock masses to mega-blocks to large blocks; mapped as younger Quaternary landslide and flow deposits (Qms, Qmf) where blocks are smaller and are “floating” in rubble; shown as complex thrust faulting in previous mapping (see Baker, 1964a, 1972a).

Taf **Tertiary alluvial-fan deposits** (Pliocene?) - Poorly to moderately sorted, clay- to boulder-sized material that is poorly exposed in northwest end of Round Valley graben, Charleston quadrangle; age based on less dissection than Tibble Formation; clasts weathering out of material are subangular sandstone and limestone of adjacent Oquirrh Formation; unit may be alluvial-fan deposits (age like QTa), colluvium, and regolith that mantle the Bear Canyon Member of the Oquirrh Formation; queried on slope that may be colluvium and regolith cover; estimate 0 to 650 feet (0-200 m) thick (Biek and Lowe, 2005). Not equivalent to Taf of Biek (2005b); his Taf is here mapped as Tibble Formation.

Tsl **Salt Lake Formation** (Pliocene and Miocene?) - Includes conglomeratic and lower tuffaceous lithologies; typically poorly exposed. At Jordan Narrows upper lithosome is light-brown to reddish-brown mudstone, siltstone, and lesser fine-grained sandstone and pebble conglomerate about 450+ feet (135 m) thick; lower lithosome is white to light-gray tuffaceous marlstone and micrite, lesser limestone, minor claystone, sandstone, and rhyolitic tuff; lower lithosome includes thin volcanic ash (tuff) beds composed almost entirely of glass shards; about 1500 feet (500 m) thick. Near Payson, outcrops are conglomerate, with quartzite, limestone and volcanic clasts, and volcaniclastic sandstone.

Tb **Mosida Basalt** (Miocene) - Medium-dark-gray, porphyritic, trachybasalt lava flow; phenocrysts of olivine, plagioclase, and clinopyroxene; unexposed vent near Soldiers Pass; $^{40}Ar/^{39}Ar$ ages of 19.47 $\pm$ 0.14 and 19.65 $\pm$ 0.17 Ma (table 1); 0 to 120 feet (35 m) thick (Christiansen and others, 2007).

Tic, Tict

Little Cottonwood Stock (Oligocene) - Porphyritic quartz monzonite with potassium feldspar phenocrysts 1 to 3 inches (2.5-7.5 cm) in diameter in a holocrystalline, medium-grained groundmass of plagioclase, quartz, and orthoclase and some biotite and hornblende; intrusive age based on U-Pb zircon analysis is 30.5 $\pm$ 0.6 Ma (Vogel and others, 1997, table 2; Constenius, 1998). Tict used for tectonite of altered and fractured rock along faulted carapace of stock.

Tvtw **Volcanic rocks of west Traverse Mountains** (Oligocene) - Volcanic debris flow/lahar breccia and tuff, lesser lava flows and ash-flow tuffs, and minor fluvial volcanic-sedimentary rocks; intermediate composition; probable age range of 31 to 33 Ma (Waite and others, 1997); plagioclase $^{40}Ar/^{39}Ar$ age 32.12 $\pm$ 0.14 Ma in adjacent Tickville Spring quadrangle (Deino and Keith, 1997, TICK-28); probably from local vents including the Step Mountain andesite plug, South Mountain area, and other smaller vents; 1000+ feet (300+ m) thick.

Tsp **Soldiers Pass Formation, undivided** (lower Oligocene - upper Eocene) - Part of the Soldiers Pass volcanic field; upper part of shoshonitic brecciated lava with coeval lacustrine limestone and claystone (breccia member and White Knoll Member); intermediate lava flow (andesite member); rhyolitic ash-flow tuff with abundant pumice fragments (Chimney Rock Pass Tuff Member); lowest part is trachydacite tuff member; $^{40}Ar/^{39}Ar$ ages from 33.73 $\pm$ 0.65 to 34.79 $\pm$ 0.10 Ma (table 1); 0 to about 500 feet (150 m) thick (Christiansen and others, 2007).

Ti **Intrusive rocks** (Miocene - Oligocene) - Biotite-bearing, dark-gray, medium- to fine-grained quartz diorite (Baker, 1976) that intrudes Granger Mountain Member of Oquirrh Formation and probably the Uinta Formation (middle Eocene); $^{40}Ar/^{39}Ar$ biotite age of 34.7 ± 0.16 Ma (sample KNC90299-1, table 1) puts the intrusion in the age range of volcanic rocks in map area (table 1) and the older potassic mafic rocks (lamproites) to the north (34-35 Ma) (Mitchell and Bergman, 1991); exposure is in Second Set Canyon south wall (section 12, T. 6 S., R. 5 E., Twin Peaks quadrangle) and is several hundred feet wide and about 1500 feet (460 m) long, elongate to the northwest.

Tt **Tibble Formation** (lower Miocene?, Oligocene, and upper Eocene) - Brick-red, red-brown, and gray, cobble to boulder conglomerate; lithic clasts predominantly Pennsylvanian-Permian sandstone and quartzite, but in upper Tibble in type area include Paleozoic clasts from footwall of the Deer Creek detachment and volcanic clasts; largest boulders about 6 feet (2 m) across; intercalated with variegated brick-red and gray mudstone, bentonitic mudstone, and poorly sorted sandstone; minor white to light-gray tuffaceous sandstone and medium-gray microcrystalline limestone; rare thin beds of light-gray tuff; the Tibble is an extensional basin-fill deposit that overlies with angular unconformity, and is in fault contact with, pre-Tertiary hanging-wall rocks of the Charleston-Nebo thrust sheet; mapped in grabens in Granger Mountain, Springville, Timpanogos Cave, Aspen Grove, Lehi, and Jordan Narrows quadrangles; fossiliferous, "soft" weathering, gray shale in Pole Heaven valley, Springville quadrangle, yielded an early Miocene-Oligocene gastropod fauna (KNC052304-5); $^{40}Ar/^{39}Ar$ biotite age of 36.56 ± 0.15 Ma and U-Pb zircon age of 36.1 ± 1.7 Ma on tuff bed in Timpanogos Cave quadrangle (KNC61093-2T, tables 1 and 2); U-Pb zircon age of 33.7 ± 0.6 Ma on tuff in Granger Mountain quadrangle (KNC053107-3, table 2); thickness 0 to 2500 feet (0-760 m).

May be age-equivalent of upper Eocene-lower Oligocene and Miocene non-conglomeratic strata (Gerald Waanders, consulting palynologist, 2008, written communication) encountered below about 10,000 feet (3000 m) in Gulf Banks well in Utah Valley near Spanish Fork.

Tvb **Boulder conglomerate** (Oligocene and upper Eocene?) - Conglomerate with clasts of volcanic rocks, quartzite, and lesser dolomite and limestone in a matrix of light-gray volcanic ash and sand; age, source and correlation unknown, but clasts are similar to strata exposed in the East Tintic Mountains; present near mouth of Payson Canyon; 400+ feet (120+ m) thick (Solomon and others, 2007).

Tvte **Volcanic rocks of East Traverse Mountains** (Oligocene - upper Eocene) - Interbedded ash-flow tuff, volcanic debris flow/lahar breccia, minor lava flows, and minor fluvial volcano-sedimentary rocks; intermediate composition, poorly exposed and locally extensively altered; chemically similar to the Keetley Volcanics and some intrusions in the Wasatch igneous belt; probable age range of 33 to 39 Ma; $^{40}Ar/^{39}Ar$ age of 35.25 ±

0.13 Ma from Maple Hollow (table 1) (Biek, 2005b); about 1000 feet (300 m) thick. Includes younger pebble dikes that cut these rocks. Includes volcaniclastic rocks in Tibble graben with U-Pb zircon age of 35.7 ± 0.6 Ma on andesite porphyry in Timpanogos Cave quadrangle (KNC060407-14, table 2); thickness uncertain, confined to graben.

Tm **Moroni Formation** (Oligocene - upper Eocene) - Very light gray, gray, and white, tuffaceous and pumiceous sandstone and tuff interbedded with lesser conglomerate, pumice, welded tuff, and limestone; conglomerate clasts vary from pebbles and cobbles to small boulders (~20 inches [0.5 m]); sedimentary clasts from Permian-Pennsylvanian Oquirrh Formation, Permian Diamond Creek Sandstone and Park City Formation, and Cambrian Tintic Quartzite; volcanic clasts predominantly gray to very dark-gray, reddish brown-weathering andesite-dacite porphyry; tuffs and tuffaceous sandstones poorly exposed, conglomerate bed in lower part of unit is ledge forming and about 65 feet (20 m) thick; formation rests unconformably on Tu; top removed by erosion, 0 to an estimated 1800 feet (~550 m) thick; mapped as Tibble Formation by Young (1976) and called Wanrhodes volcanics by Neighbor (1959); like Tibble is extensional graben-fill, but contains more volcanic material than Tibble (see above); samples KNC71194-5, KNC101701-1, and KNC101701-4 from Billies Mountain quadrangle were $^{40}Ar/^{39}Ar$ dated at 34.68 ± 0.09, 34.86 ± 0.09, and 37.18 ± 0.38 Ma, respectively (table 1).

Tk **Keetley Volcanics** (Oligocene? - upper Eocene) - Volcanic breccia and conglomerate in upper part, interbedded volcanic conglomerate and minor light-gray tuffaceous sandstone in lower 300 feet (90 m); volcanic clasts are andesite to rhyodacite; conglomerate has light-orange and gray, coarse sandstone matrix and locally contains orthoquartzite, sandstone, and limestone boulders to pebbles; tuffaceous sandstone is light gray, coarse grained to pebbly, and trough cross-bedded; sample KNC92799-5 from Co-op Creek quadrangle yielded an $^{40}Ar/^{39}Ar$ age of 40.45 ± 0.18 Ma (table 1); 0 to more than 1400 feet (0-430+ m) thick. Includes mixed (Oquirrh and volcanic rock) clast unit Ta of Biek and others (2003). Keetley Volcanic units were previously K-Ar (biotite) dated by Crittenden and others (1973) at 34.0 ± 1.0 Ma for a sample (62-mc-15) from the Wolf Creek Summit quadrangle in the map area; they also reported K-Ar biotite ages of 35.1 ± 1.1 and 32.7 ± 1.0 Ma for other Keetley Volcanic units to the north of the Provo 30x60-minute quadrangle near Jordanelle and Francis, respectively.

Tkq **Keetley Volcanics, quartzite clast unit** (Oligocene? - upper Eocene) - Gray tuffaceous volcanic sandstone matrix with granules to boulders of Oquirrh Formation quartzite and some limestone; locally contains Mesozoic rock clasts from sand to gravel size that form sedimentary sandstone and sandstone matrix; only mapped separately in the Center Creek quadrangle where it is distinct because it lacks volcanic clasts; 0 to about 450 feet (0-140 m) thick, but thickness may include interbedded volcanic strata.

Tkt **Keetley Volcanics, basal tuffaceous unit** (Oligocene? - upper Eocene) - Very light gray to greenish-gray tuff and tuffaceous sandstone and pebbly sandstone; rarely exposed; sample KNC92799-6 from Co-op Creek quadrangle yielded an $^{40}Ar/^{39}Ar$ age of 37.25±0.14 Ma (table 1); another sample (KNC6901-1), from near Peoa, Utah, yielded an $^{40}Ar/^{39}Ar$ age of 38.20 ± 0.11 Ma (Constenius and others, 2003); 0 to about 200 feet (0-60 m) thick in northeast part of map area; may be as much as 800 feet (240 m) thick in Center Creek quadrangle if bedding dip in area is minimal (after Biek and others, 2003).

Tvc **Volcaniclastic rocks of Strawberry Valley** (Oligocene? - upper Eocene) - Upper part is tan to orange and gray conglomerate and coarse-grained sandstone; conglomerate contains quartzite cobbles to small boulders with sandstone, limestone, and volcanic clasts locally present. Lower part is light-gray, boulder to cobble conglomerate with quartzite and andesite to rhyodacite clasts in a coarse to pebbly sandstone matrix; interbedded with light-gray, coarse-grained, cross-bedded, tuffaceous sandstone. Correlative northward to Keetley Volcanics and possibly southward to Moroni Formation; sample KNC92899-2 from Co-op Creek quadrangle was $^{40}Ar/^{39}Ar$ dated at 37.73 ± 0.28 Ma (table 1); at least 1500 feet (460 m) thick, with top not exposed.

Tucb **Uinta Formation, boulder conglomerate** (late middle Eocene) - Red-brown and gray, thick- to very thick bedded conglomerate, commonly stained red by weathering of interbedded, thin, red-brown and brick red mudstone; extremely coarse clastic unit composed mainly of cobbles and boulders, some very large (3 to 10 feet [1-3 m] diameter); quartzite clasts derived from Permian-Pennsylvanian Oquirrh Formation predominate, with Precambrian Uinta Mountain Group, Cambrian Tintic Quartzite, Pennsylvanian Weber Formation, Permian Park City Formation, Triassic Thaynes Formation, and Jurassic Twin Creek Limestone lithic clasts locally present in the Red Ledge (eastern Co-op Creek quadrangle) and White Ledge (southeast Wolf Creek Summit quadrangle) areas; sandstone occurs as minor intercalated lenses of coarse- to very coarse grained, brick-red to red-brown sandstone; mudstone is brick red to red brown and forms thin partings between ledges of conglomerate; partings of bentonite are found at White Ledge locality between light-gray, buff weathering beds of cobble-boulder conglomerate; unit found above ~8800’ capping landscape prominences in the Twin Peaks, Co-op Creek, and Wolf Creek Summit quadrangles; overlies conglomerate member of Uinta Formation; samples KNC070109-1 and KNC070109-2 from White Ledge in Wolf Creek Summit quadrangle yielded a U-Pb zircon ages of 38.9 ± 0.8 Ma and 39.6 ± 0.7 Ma, respectively (table 2); preserved thickness ranges from about 500 to 900 feet (150-275 m).

Tuc **Uinta Formation, conglomerate** (middle Eocene) - Red-brown, tan and gray, thick- to very thick bedded pebble-cobble conglomerate interbedded with minor sandstone, commonly stained red by weathering of interbedded, thin, red-brown mudstone; quartzite clasts predominantly derived from Permian-Pennsylvanian Oquirrh Formation; sandstone is subordinate to conglomerate and occurs as intercalated lenses of coarse- to very coarse grained, brick-red to red-brown sandstone; mudstone is brick red to red brown and forms thin partings between ledges of conglomerate; interfingers with the main body of the Uinta Formation eastward and southward over short distances; up to 1500 feet (460 m) thick.

Tu **Uinta Formation, main body** (middle Eocene) - Includes: (1) light-gray, tan, and red, medium- to thick-bedded, lenticular-bedded, pebbly sandstone; (2) brick-red, reddish-brown, variegated, very thick to thin-bedded mudstone, commonly with floating sand grains; (3) red-brown, tan, and gray conglomerate with sandstone to mudstone matrix; and (4) dark-gray to yellowish- and purplish-gray marlstone of probable pedogenic origin; interfingers northward with overlying Tuc and underlying Tuc; also interfingers westward with overlying Tuc; at least 2000 feet (600 m) exposed.

Tgu **Green River Formation, upper member** (middle Eocene) - Sandstone, siltstone, mudstone, marlstone, and minor oil shale. Sandstone is light gray, light-brown-weathering, calcareous, and medium to thick bedded; some beds are trough cross-stratified and fine to medium grained, grading to siltstone; occasionally coarse-grained to conglomeratic. Marlstone is dark gray, weathering to light tan, light gray, or gray, thin to thick bedded, and microcrystalline. Mudstone is predominantly greenish gray to dark gray and poorly exposed. Oil shale is rare, grayish brown to dark brown, and fissile. Sandstone and marlstone form steep slopes and cliffs, with thin benches along oil shale and mudstone horizons. More than 400 feet (120 m) thick at Island Mountain where the base of the unit is not exposed. Unit progressively truncated and is completely removed by erosion to the west in the Billies Mountain and Two Tom Hill quadrangles along the basal Uinta Formation unconformity.

Tgm **Green River Formation, middle member** (middle Eocene) - Lower part is dominantly dark-brown, light-bluish-gray-weathering, fissile to platy, thinly laminated oil shale and marlstone; upper part is mostly greenish-gray and gray mudstone, gray siltstone, and tan, fine- to medium-grained sandstone; distinctive small steel-blue to dark-bluish-gray concretions throughout; at least 2200 feet (670 m) thick in complete sections. Unit progressively truncated and is completely removed by erosion to the west in the Billies Mountain and Two Tom Hill quadrangles along the basal Uinta Formation unconformity.

Tgl **Green River Formation, lower member** (middle Eocene) - Greenish-gray, fissile to blocky shale and mudstone as very thick beds separated by thinly laminated, gray marlstone; also contains gray-green, waxy-textured claystone and thin-bedded, brown-weathering sandstone that is locally micaceous; sandstone contains rare vertebrate fossils as lags (gar scales, turtle and crocodile plates); oil shale is common near base; at least 1200 feet (365 m) thick in complete sections. Unit progressively truncated and is completely removed by erosion to the west in the Billies Mountain and Two Tom Hill quadrangles along the basal Uinta Formation unconformity.

Tc **Colton Formation** (lower Eocene) - Medium- to coarse-grained, light-gray, light-brown-weathering, calcareous sandstone in thin to thick beds; interbedded with medium-gray, microcrystalline limestone, and red-brown, gray and gray-green mudstone; top of formation in Rays Valley quadrangle is at the top of an extremely fossiliferous sandstone bed containing *Unionidae* bivalves, gastropods, and vertebrate fossils (gar scales, crocodile teeth, crocodile and turtle plates and bones); about 170 feet (50) m thick.

Tf **Flagstaff Limestone** (lower Eocene) - Medium-gray, very thick bedded, microcrystalline limestone; weathers white and light gray; hard and brittle; forms cliffs; interbedded with less-resistant, variegated brick-red, purplish-gray, maroon, red-brown, yellow and gray marlstone and calcareous mudstone; light-gray, thin- to medium-bedded, medium- to coarse-grained sandstone increases in abundance up section; about 280 feet (85 m) thick.

Ts **Tertiary sedimentary rocks** (Eocene? and/or Paleocene?) - Red-orange mudstone, gray conglomerate, light brown limestone; conglomerate with pebbles to boulders of quartzite and limestone; locally includes oncolitic and algal limestone that is medium to irregularly bedded; caps West Mountain and exposed at mouth of Payson Canyon; up to 240 feet (75 m) thick (Clark, 2009).

Tn **North Horn Formation, upper member** (lower Eocene - upper Paleocene) - Brick-red, thick- to very thick bedded mudstone, siltstone, and sandstone; interbedded with very thick bedded, medium-gray-weathering, microcrystalline limestone; upper limestone beds contain fossil gastropods and bivalves that date the unit (see Constenius, 2008); conglomerate locally present as thick, lenticular, channel-fill deposits containing pebbles to rare boulders of Permian-Pennsylvanian Oquirrh Formation; about 200 feet (60 m) thick. At the mouth of Spanish Fork Canyon, includes brick-red and red-brown sandstone and pebble conglomerate with predominantly clasts of Oquirrh Formation sandstone/quartzite and limestone; exposed thickness 0 to about 400 feet (0-120 m), but up to 780 feet (240 m) thick in subsurface (Constenius, 2008).

TKnq **North Horn Formation, quartzite conglomerate member** (Paleocene and Upper Cretaceous, Maastrichtian) - Light-gray, thick- to very thick bedded, cobble to boulder (up to about 3 feet [1 m] across) conglomerate with dominantly well-rounded, gray and tan quartzite clasts from the Oquirrh Formation; intercalated with light-gray, yellow-tan-weathering, and minor brick-red, medium- to coarse-grained sandstone; limonitic staining common; upper contact conformable with Tn; lower contact is profound angular unconformity with Permian rocks; present in Granger Mountain area; mapped separately from TKn to emphasize clast content, location, and unconformity; 0 to 250 feet (0-75 m) thick.

TKn **North Horn Formation, lower member** (upper Paleocene - Upper Cretaceous, Maastrichtian) - Light- to medium-gray or brick-red or red-brown conglomerate, commonly discolored by red-colored slopewash from thin, interbedded, red mudstone; intercalated with light-gray, yellow-tan weathering, medium-coarse grained sandstone; clasts of Oquirrh Formation sandstone, quartzite, and limestone predominate; palynomorphs from rare lignite and carbonaceous shale indicate a late Paleocene age (see Horton and others, 2004; Constenius, 2008); lower contact is profound unconformity (see also Constenius and others, 2003); at least 1800 feet (550 m) thick.

TKc **Currant Creek Formation** (Paleocene - Upper Cretaceous, Maastrichtian) - Includes: gray- to tan-weathering, thick-bedded, boulder to cobble conglomerate, dominated by well-rounded, quartzite clasts from Oquirrh Formation; gray, yellowish-gray, and minor red, thick-bedded, coarse-grained sandstone and pebble conglomerate; and gray, very light gray and variegated siltstone; only in northeast part of map area; unconformably overlies Mesaverde Formation; about 4800 feet (1460 m) thick near Currant Creek (Bissell, 1952); see also Walton (1944), 4000 feet (1200 m) thick in same area.

Kpc **Price River Formation and Castlegate Sandstone** (Upper Cretaceous, Maastrichtian-Campanian) - Light-gray, thick- to very thick bedded, cobble to boulder conglomerate, dominated by well-rounded, gray and tan, quartzite clasts; largest boulders exceed 10 feet (3 m) across; minor intercalated sandstone; conglomerate contains light silvery-gray sandstone matrix characterized by white, smooth- to earthy-textured, clay blebs; lithic clasts >99% Permian-Pennsylvanian Oquirrh Formation quartzite, quartzite clasts derived from Proterozoic Mutual Formation and Cambrian Tintic Quartzite present in trace amounts; overlain and underlain with angular unconformity by TKn and Kcm (and older units), respectively, where exposed in Billies Mountain area; thickness ranges from 0 to 2000 feet (0 to 600 m).

Kmv **Mesaverde Formation** (Upper Cretaceous) - Light-gray, white, and tan, thick-bedded, cross-bedded, coarse-grained sandstone, gray siltstone, and dark-brownish-gray, carbonaceous shale and coal; 5165 feet (1575 m) thickness measured by Bissell (1952) in Currant Creek drainage.

Km **Mancos Shale** (Upper Cretaceous) - Dark-gray, bentonitic shale with minor gray limestone and gray, fine-grained sandstone; very poorly exposed; 1680 feet (512 m) thickness calculated by Bissell (1952) near Currant Creek Reservoir.

Kf **Frontier Formation** (Upper Cretaceous) - Light-gray, white, and tan, thick-bedded, medium-grained sandstone interbedded with dark-gray siltstone, shale, dark-brownish-gray, carbonaceous shale and minor coal in upper part; contains an oyster coquina marker bed in the lower 50 feet (15 m); extensively burrowed in the middle; about 700 feet (215 m) thick in northeast part of map area (this report; see also Bissell, 1952, his Frontier plus his lower Mancos Shale and limestone at top of his Mowry). Very poorly exposed in Center Creek quadrangle.

Kmm **Mancos Shale, Mowry Shale Tongue** (Lower Cretaceous) - Dark-gray, platy to blocky, fissile, siliceous shale in lower part, with abundant teleost fish scales. Upper part contains non-fissile, greenish-gray claystone; about 90 feet (25 m) thick in northeast part of map area (this report; see units 1-3 of Bissell, 1952).

Kd **Dakota Formation** (Lower Cretaceous) - Sandstone, white to tan, very thick bedded, cross-bedded, with extensive quartz veins; interbedded with gray and variegated siltstone; thickens northward from about 200 to 400 feet (60-120 m) in northeast part of map area (this report; see also Bissell, 1952).

Kcm **Cedar Mountain Formation** (Lower Cretaceous) - Mapped separately in Billies Mountain quadrangle. Variegated greenish-gray, red-brown, and lavender mudstone, interbedded with gray, red, and buff, coarse- to fine-grained sandstone and siltstone; minor nodular limestone and conglomerate; 465 feet (142 m) thick (Young, 1976). Likely includes Morrison Formation strata and unconformity between Cedar Mountain and Morrison.

KJcm **Cedar Mountain** (Lower Cretaceous) **and Morrison** (Upper Jurassic) **Formations, undivided** - **Cedar Mountain**, see above. **Morrison** - Interbedded greenish-gray and light-red siltstone and medium-grained, pinkish-gray sandstone and some pinkish-gray, quartz- and chert-pebble conglomerate and pebbly sandstone in thick, fining-upward, trough-cross-stratified beds; base not exposed; up to 2500 feet (760 m) thick in southeast Heber Mountain quadrangle (this report; see also "Morrison" of Bissell, 1952).

Jsv **Summerville Formation** (Middle Jurassic) - Red-orange mudstone, siltstone, and sandstone; only mapped in Billies Mountain quadrangle and conformably overlies Curtis Formation; see Imlay (1980) for correlation; 395 feet (120 m) thick (Young, 1976).

Js **Stump Formation** (Middle Jurassic) - Light-gray, medium-bedded, calcareous sandstone in lower part; gray to green-gray, thick-bedded, ridge-forming, bioclastic limestone and sandy limestone in upper part; about 250 feet (75 m) thick in Wolf Creek Summit quadrangle.

Jce **Curtis and Entrada Formations, undivided** (Middle Jurassic) - Only mapped in Billies Mountain quadrangle; lateral equivalent of lower (Curtis Member of) Stump and Preuss Formations; see Imlay (1980) for more information. **Curtis** - Greenish-gray, sandy shale, mudstone, and sandstone, with minor dark-red-brown sandstone; about 400 feet (120 m) thick. **Entrada** - Dark-red, red-brown, and purplish red-brown, with minor light-gray and light-brown, thin- to medium-bedded sandstone and siltstone; about 1000 feet (300 m) thick.

Jp **Preuss Formation** (Middle Jurassic) - Red, brownish-red, purplish red, and minor light-gray, thin- to medium-bedded sandstone and siltstone; poorly exposed; about 750 feet (230 m) thick in Wolf Creek Summit quadrangle.

Ja **Arapien Shale** (Middle Jurassic) - Light-gray-green and light-gray shale interbedded with light-gray, tan-weathering, ripple cross-laminated, calcareous siltstone and sandstone; minor interbeds of red shale, light-yellow-gray sandstone, and gray-green to brown, micritic limestone; thickness about 560 feet (170 m); only mapped in Billies Mountain quadrangle, equivalent to unit Jtgl.

Jtc **Twin Creek Limestone, undivided** (Middle Jurassic) - Used in Center Creek quadrangle; Arapien-Twin Creek interval 1200 feet (370 m) thick south of map area in Spanish Fork Canyon (Baker, 1947; Imlay, 1967) and likely about the same thickness here. See correlation chart for map-unit subdivisions.

Jtu **Twin Creek Limestone, upper members** (Middle Jurassic) - Mapped in Co-op Creek and Heber Mountain quadrangles where upper Twin Creek is structurally attenuated and top not exposed; divided into units Jtgl and Jtw elsewhere; estimated undeformed thickness about 650 feet (200 m) from regional relationships.

Jtgl **Twin Creek Limestone, Giraffe Creek and Leeds Creek Members** (Middle Jurassic) - Thinly interbedded, light-gray to light-greenish-gray, soft, shaly limestone and platy weathering, light-gray to tannish-gray, fine-grained calcareous sandstone; sandstone increases upward; a 15-foot-thick (5 m) gypsum bed lies in the middle of the unit; about 500 feet (150 m) thick in Wolf Creek Summit quadrangle and northeast parts of map area.

Jtwl **Twin Creek Limestone, Watton Canyon, Boundary Ridge, Rich, Sliderock, and Gypsum Spring Members** (Middle Jurassic) - Unit only used in Billies Mountain quadrangle where Giraffe Creek and Leeds Creek Members are indistinct and were shown by some workers as the Arapien Shale; about 600 feet (180 m) thick (Imlay, 1980).

Jtw **Twin Creek Limestone, Watton Canyon Member** (Middle Jurassic) – Dark-gray, medium- to thick-bedded, lime micrite to wackestone with oolites and pelecypod fragments; resistant ridge former; micrites display characteristic spaced, bedding-normal fracture cleavage; about 120 feet (35 m) thick in Wolf Creek Summit quadrangle and thicker to west, about 250 feet (75 m) thick in northwest Charleston quadrangle (Biek and Lowe, 2005) and about 350 feet (110 m) thick in east Billies Mountain quadrangle (after Young, 1976).

Jtl **Twin Creek Limestone, lower members** (Middle Jurassic) - Unit used in Co-op Creek and Heber Mountain quadrangles where lower Twin Creek is structurally attenuated; divided into units Jtb and Jtrsg elsewhere; estimated undeformed thickness is about 230 feet (70 m) from regional relationships.

Jtb **Twin Creek Limestone, Boundary Ridge Member** (Middle Jurassic) - Red to purplish-red shale and siltstone, and minor gray siltstone; recessive and poorly exposed; about 65 feet (20 m) thick in Wolf Creek Summit quadrangle and thicker to west, about 120 feet (35 m) thick in northwest Charleston quadrangle (Biek and Lowe, 2005) and 200 feet (60 m) measured in east Billies Mountain quadrangle (Young, 1976).

Jtrsg **Twin Creek Limestone, Rich, Sliderock and Gypsum Spring Members** (Middle Jurassic) - Light-gray, soft, shaly limestone in upper part; dark-gray, thick-bedded, bioclastic limestone in middle, and thin (5-foot [1.5-m] thick) purple shale at base; about 160 feet (50 m) thick in Wolf Creek Summit quadrangle and thicker to west, about 420 feet (125 m) thick in northwest Charleston quadrangle (Biek and Lowe, 2005) and 455 feet (140 m) thick measured in east Billies Mountain quadrangle (Young, 1976).

Jn **Nugget Sandstone** (Lower Jurassic) - Reddish-orange, orange, and pink, massive-weathering, cross-bedded, moderately cemented to friable, noncalcareous, fine- to medium-grained sandstone, with well-rounded commonly frosted grains; Navajo of some previous workers; about 1260 to 1450 feet (385-440 m) thick (this report; Baker, 1947).

TRa **Ankareh Formation** (Upper and Lower[?] Triassic) - Dull-red, reddish-brown and purple, thin-bedded mudstone, siltstone, and medium- to thin-bedded, fine-grained sandstone; siltstone is locally micaceous; green reduction spots common; in Co-op Creek quadrangle, part of the lower Ankareh is included in unit TRat (see below); to the west, Baker (1947) reported a total thickness of 1485 to 1530 feet (453-466 m) in the Wasatch Range; Bissell (1952) measured 1535 feet (468 m) in the Wolf Creek Summit quadrangle.

TRau **Ankareh Formation, upper member** (Upper Triassic) - Red, purplish-red, and reddish-gray, thin-bedded mudstone, siltstone, and fine-grained sandstone; about 350 (110 m) feet thick in Wolf Creek Summit quadrangle and 450 feet (135 m) thick in Aspen Grove quadrangle (Baker, 1964a).

TRam **Ankareh Formation, middle member** (Upper Triassic) - Gray to white, very thick bedded, cross-bedded, coarse-grained sandstone and pebble conglomerate; about 40 feet

(12 m) thick (this report; Baker, 1964a); possibly equivalent to the Gartra Grit Member and called Shinarump by some previous workers (for example Bissell, 1952).

TRal **Ankareh Formation, lower member** (Lower Triassic) - Red and purple siltstone and shale, and purplish-gray, calcareous siltstone; thin bedded throughout; poorly exposed; about 800 feet (245 m) thick in Wolf Creek Summit quadrangle; in Aspen Grove quadrangle, 1000 foot (300 m) thickness reported by Baker (1964a), while Smith (1969) reported 1372 foot (420 m) thickness.

TRat **Lower Ankareh Formation and upper Thaynes Formation, undivided** (Lower Triassic) - Only used in structurally complicated Co-op Creek quadrangle; greenish-gray and very light gray, calcareous sandstone with green clay intraclasts in upper part; white, thinly laminated, well-indurated, calcareous sandstone and micaceous sandstone in lower part; unit contains rocks that are transitional between typical lower Ankareh and upper Thaynes lithologies; U-Pb zircon age of 249 ± 3.0 Ma on tuff from Co-op Creek quadrangle (JC 99-37, table 2) implies tuff is more likely Thaynes Formation age; north of the map area Kummel (1954, figure 21) portrayed the formations as intertonguing; about 350 feet (110 m) thick.

TRt **Thaynes Formation, undivided** (Lower Triassic) - Greenish-gray to brownish-gray, thin-bedded, silty limestone and fine-grained, calcareous sandstone; only used in northeast corner of map area, where top not exposed, and in Billies Mountain quadrangle; subdivided elsewhere. Neighbor (1959) reported a dip-corrected, subsurface thickness of 1450 feet (440 m) in Billies Mountain quadrangle and Baker reported 1340 feet (410 m) thickness measured nearby; in Aspen Grove quadrangle, reportedly only 950 feet (290 m) thick (Baker, 1964a) and 1126 feet (345 m) thick (Smith, 1969). Smith's (1969) members are similar to those used elsewhere in map area; Bissell (1952, only units 1-4) reported 1210 feet (370 m) total thickness.

TRtu **Thaynes Formation, upper member of Smith (1969)** (Lower Triassic) - Gray siltstone with some grayish-green shale and gray limestone; 446 feet (136 m) thick in Aspen Grove quadrangle (Smith, 1969). About 775 feet (235 m) penetrated (not dip corrected) in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished), but high dip. Includes some or all of unit TRat.

TRad **Ankareh Formation, Decker tongue of Smith (1969)** (Lower Triassic) - Poorly exposed dark-red to brownish-red siltstone and silty shale with minor fine-grained sandstone at type area in Aspen Grove quadrangle; 222.5 feet (68 m) thick but may be faulted (Smith, 1969). About 220 and 320 feet (65 and 100 m) penetrated (not dip corrected) in Sun Oil Diamond Fork #2 well and Amoco Cottonwood Canyon well, respectively (after Welsh, 1981, unpublished), but high dip in Amoco well. Smith's

(1969) Decker tongue at Willow Creek, Co-op Creek quadrangle is unit 3 of Bissell (1952).

TRtl **Thaynes Formation, lower member of Smith (1969)** (Lower Triassic) - Gray siltstone and limestone; 457 feet (140 m) thick in Aspen Grove quadrangle (Smith, 1969). About 600 feet (180 m) and 1040 feet (320 m) penetrated (not dip corrected) in Sun Oil Diamond Fork #2 well and Amoco Cottonwood Canyon well, respectively (after Welsh, 1981, unpublished), but moderate dip in Amoco well.

TRtu **Thaynes Formation, upper member** (Lower Triassic) - Dark-gray, bioclastic, lime grainstone; weathers medium blue gray; forms two prominent ridges separated by thin-bedded, dark-gray, silty limestone; about 300 feet (90 m) thick in Co-op Creek area (this report; see also Bissell, 1952, unit 4).

TRtla **Thaynes Formation, lower member, and Ankareh Formation** (Lower Triassic) - Mainly dark-brownish-red, thin- to medium-bedded, calcareous siltstone with rare zones of dark-gray, blue-gray weathering, bioclastic grainstone resembling unit TRtu in lower part; about 1000 feet (300 m) thick in Co-op Creek area, and structurally thickened in Heber Mountain quadrangle (this report; see also Bissell, 1952, units 1-3). Mixed lithologies imply intertongued Thaynes and Ankareh, including unit TRad.

TRw **Woodside Shale** (Lower Triassic) - Dark-red to red-brown shale and siltstone; poorly exposed; forms strike valleys; 420 to 600 to 735 feet (130 to 180 to 233 m) thick in northeast part of map area (this report; Bissell, 1952; Neighbor, 1959; after Smith, 1969). About 870 feet (265 m) and 780 feet (240 m) penetrated (not dip corrected) in Sun Oil Diamond Fork #2 well and Amoco Cottonwood Canyon well, respectively (after Welsh, 1981, unpublished); about 770 feet (235 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (< 8 degrees dip); queried in Wallsburg Ridge quadrangle because, as mapped, unit is less than 200 feet (<60 m) thick. Structurally thinned along Little Diamond Creek fault system, and appears far thinner, less than 200 feet (<60 m) thick, than regional minimum in Wallsburg Ridge quadrangle (hence query); about 500 feet (150 m) thick in Aspen Grove quadrangle (Smith, 1969 after Baker, 1964a).

Thin Paleozoic Strata in Footwall of Charleston-Nebo Thrust System

These strata include thinner exposed versions of Permian and Pennsylvanian rocks (see following), the Pennsylvanian Round Valley Limestone, and the Mississippian Doughnut, Humbug, Deseret, and Gardison Formations (after Huddle and McCann, 1947a,b; Baker and others, 1949; Bissell, 1952), as well as lower Paleozoic strata (Fitchville Formation and/or Devonian rocks and Cambrian Maxfield, Ophir, and Tintic Formations (after Huddle and others, 1951). The Permian and Pennsylvanian strata are likely as thin in subsurface east of Charleston-Nebo thrust faults in the east part of map area (see lithologic column).

Pp **Park City and Phosphoria Formations, undivided** (Permian) - Consists of upper [Franson Member of Park City Formation], middle [Meade Peak Member of Phosphoria Formation] and lower [Grandeur Member of Park City Formation] units that are 352, 60, and 458 feet (107, 18, and 140 m) thick, respectively, just north of the Aspen Grove quadrangle (Baker, 1964a); in Center Creek quadrangle below the Charleston-Nebo thrust in the Placid-Daniels well, same units are about 165, 55, and 405 feet (50, 17, and 123 m) thick; in Wolf Creek quadrangle total thickness reportedly about 450 feet (140 m) (Bissell, 1952) and greater than 600 feet (180 m) thick (Smith and others, 1952); though about one-half the exposed thicknesses, units are lithologically like their counterparts (Ppf, Ppm, Ppg) of thick upper Paleozoic strata in map area.

IPw **Weber Quartzite** (Lower? Pennsylvanian) - Mainly gray to buff, quartz-cemented sandstone with some interbedded gray cherty limestone (Baker, 1964a); excessively thick in the Aspen Grove quadrangle compared to areas to north (8000 feet [2440 m] versus 1000 to 3500 feet [300-1070 m]) (after Baker, 1964a), suggesting a transition northward out of the Oquirrh basin onto continental shelf or structural thickening in the Aspen Grove area; east of map area, about 1600 feet (490 m) thickness exposed along Duchesne River (Bissell, 1952).

IPrv **Round Valley Limestone** (Lower Pennsylvanian) - Light- to medium-gray limestone with black, white, and orange-red chert and some thin beds of buff to gray sandstone; 225 to 400 feet (70-120 m) thick just north of Aspen Grove quadrangle (Baker, 1964a).

Mdo, Mdot

Doughnut Formation (Upper Mississippian, Chesterian?) - Gray to dark-gray, thin-bedded limestone overlying black shale with some interbedded thin, fine-grained, gray, quartzose sandstone beds (after Baker, 1964a); thickness uncertain, 1300 feet (400 m) thick just north of Aspen Grove quadrangle, but only 400 feet (120 m) thick farther north away from Charleston-Nebo thrust (Crittenden, 1959; Baker, 1964a); again, this suggests a transition northward out of the Oquirrh basin onto continental shelf or structural thickening, here with upper carbonate part likely structurally thickened while lower shale part is structurally attenuated. Mdot used along Deer Creek fault where unit is marble (see Biek, 2005b); may be related to faulting (tectonite) and/or Cottonwood stock (tactite); see also unit Tict.

Mh **Humbug Formation** (Upper Mississippian) - Incomplete dip-slope exposure, so see Mh under Thick Upper Paleozoic Strata.

Thick Upper Paleozoic Strata in Hanging wall of Charleston-Nebo Thrust System

Pp **Park City and Phosphoria Formations, undivided** (Permian) - Variably faulted out in the Spanish Fork Peak and Billies Mountain quadrangles by the Little Diamond Creek fault system; for descriptions see following subdivisions.

Ppf **Park City Formation, Franson Member** - Dolomite; light tannish gray; weathers very light tannish gray to white; very thick bedded; silty to sandy; with small, quartz-filled vugs and light-gray, white, and tan chert as nodules and stringers; commonly highly fractured to brecciated; estimate about 650 feet (200 m) thick at Willow Creek, Co-op Creek quadrangle; Bissell (1952, units 3-5) measured 585 feet (178 m), whereas Cheney and others (1953) measured 547 feet (167 m), and Welsh (1981, unpublished) measured about 730 feet (225 m); 820 to 930 feet (250-284 m) thick in Diamond Fork anticline and 680 feet (210 m) penetrated (not dip corrected) in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished); 660 feet (200 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (< 8 degree dip) (Constenius, 2008); and Baker and others (1949) reported more than 830 feet (>250 m) in Wasatch Range.

Ppm **Phosphoria Formation, Meade Peak Phosphatic Member** - Dark-gray to black, fissile, siliceous, locally oolitic shale and thin-bedded, medium-gray siltstone with brown and gray laminations; poorly exposed, forms benches and swales with siliceous shale and siltstone chips as float; about 190 to 225 feet (70 m) thick at Willow Creek, Co-op Creek quadrangle (Bissell, 1952, unit 2; Cheney and others, 1953;Welsh, 1981, unpublished); 240 to 320 feet (73-98 m) thick in Diamond Fork anticline and 300 feet (90 m) penetrated in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished); 267 feet (81 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (<8 degree dip) (Constenius, 2008); farther west about 210 feet (65 m) thick where not faulted out (Smith and others, 1952).

Ppg **Park City Formation, Grandeur Member** - Dominantly dolomite in upper two-thirds that is medium to dark gray, weathers very light gray, is very thick bedded, and is fine to medium crystalline, with dispersed, white, chert nodules; lower part is medium-gray, gray-weathering, shelly, dolomitic lime wackestone; both parts thick bedded, with dark-gray, 0.4- to 0.8-inch-thick (1-2 cm) chert layers; about 685 feet (210 m) thick at Willow Creek, Co-op Creek quadrangle (Bissell, 1952, unit 1; Cheney and others, 1953; Welsh, 1981, unpublished); only 270 feet (82 m) thick in Diamond Fork anticline and 790 feet (240 m) penetrated in Amoco Cottonwood Canyon well (Welsh, 1981, unpublished); 835 feet (255 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (<8 degree dip) (Constenius, 2008). Baker (1947) reported an 883-foot (269 m) thickness in the Wasatch Range.

Pdc **Diamond Creek Sandstone** (Lower Permian) - Very light gray, yellowish-brown and salmon-red-brown, very thick bedded and trough cross-bedded, fine-grained, friable sandstone, with thin-bedded, light-gray, calcareous sandstone interbeds; poorly exposed, forms swale between Grandeur and Kirkman carbonate ribs; 450 feet (137 m) thick at Willow Creek, Co-op Creek quadrangle (Welsh, 1981, unpublished). In Little Diamond Creek area, it is ledge-forming, buff- and salmon-colored, cross-bedded, medium- to coarse-grained sandstone with lesser thin-bedded, sandy limestone and dolomite; 480 feet (146 m) thick in Diamond Fork anticline and about 1320 feet (400 m) penetrated in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished); 1265 feet (386 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (<8 degree dip) (Constenius, 2008). Baker (1947) reported a 835-foot (255-m) thickness in Wasatch Range; incompletely exposed in Utah Valley northwest of Payson (Clark, 2009).

Pk **Kirkman Limestone** (Lower Permian, Leonardian and Wolfcampian) - Very light gray, gray and very dark gray, thick- to medium-bedded, nonlaminated to thinly laminated, dolomitic limestone; intraformational breccia makes up upper two-thirds of Kirkman in Wasatch Range (contains saline beds in subsurface) and consists of dark-gray to black, gray-weathering beds of rotated, thinly laminated, limestone clasts, and lighter gray beds of nonlaminated, dolomitic limestone; contains rare, thin beds of red-weathering, gray, slabby-weathering, sandy limestone; strong fetid odor when broken; some interbedded medium-gray and very pale orange calcareous sandstone and minor dark-gray shale in West Mountain; age from Clark (2009); thickness varies from 97 to 375 feet (30-115 m) on east side of the Strawberry River valley (this report; Welsh, 1981, unpublished, lower value; Bissell, 1952, upper value); 190 to 300 feet (60-90 m) thick in Diamond Fork anticline depending on contact with underlying Granger Mountain(?) Formation (after Welsh, 1981, unpublished); about 250 feet (75 m) thick in Amoco Cottonwood Canyon well (after Welsh, 1981, unpublished); 334 feet (102 m) were drilled in the Amoco Cottonwood Canyon well, Rays Valley quadrangle (<8 degree dip) (Constenius, 2008). Baker (1947) showed about 1600 feet (490 m) in the Wasatch Range; 1000+ feet (300+ m) thick in West Mountain, top faulted out (Clark, 2009). Saline strata are an interval of detachment/decollement in region, such that rocks above may be complexly folded and faulted while rocks below are little deformed.

Oquirrh Group (Lower Permian and Pennsylvanian) - Figure 2 (plate 2) shows the stratigraphic nomenclature and ages for the Oquirrh Group in the western part of this map and the Oquirrh Formation in the eastern part of this map. The columns are on different thrust sheets. Starting with this map, the Utah Geological Survey includes the Permian Curry Peak and Freeman Peak Formations in the Oquirrh Group (west/left column) to conform with the Permian Granger Mountain being part of the Oquirrh Formation (east/right column).

PIPo **Oquirrh Group, undivided** (Lower Permian and Pennsylvanian) - Quartzite exposed on Rock [Bird] Island (see Cottam in Bissell, 1963, p. 122); projecting West Mountain horst units along strike, rock most likely Pennsylvanian Butterfield Peaks Formation or Bingham Mine Formation, but Permian Freeman Peak and Curry Peak Formations are also exposed in the horst.

Pofc **Oquirrh Group, Freeman Peak and Curry Peak Formations, undivided** (Lower Permian, middle-lower Wolfcampian) - Gray and pale-orange, calcareous sandstone, lesser quartzite and medium-gray limestone, and minor dark-gray, sandy shale; sandstone is fine grained, and locally cross-bedded and well indurated; limestone interbeds are thin and locally fossiliferous, with calcite stringers and sandy intervals; conodont and fusulinid fossils used for age control (Clark, 2009); unit forms ledges and slopes; ~2000 feet (600 m) exposed thickness on West Mountain (Clark, 2009). Included in Oquirrh Group because lithologically and age correlative with Granger Mountain Member of Oquirrh Formation.

PIPgw **Oquirrh Formation, Granger Mountain and Wallsburg Ridge Members, undivided** - Used in Spanish Fork and adjacent Spanish Fork Peak quadrangles where difficult to tell members apart and fossil evidence not available to separate Permian Granger Mountain from Pennsylvanian Wallsburg Ridge.

Pogm **Oquirrh Formation, Granger Mountain Member** (Permian, Wolfcampian) - Gray, tan-weathering, limy, silty sandstone; minor beds with abundant track and trail markings; interbedded with minor gray, red, and buff quartzite, light-gray sandstone, and thick beds of gray limestone in lower part of unit; 8200 to 10,255 feet (2500-3126 m) thick on Wallsburg Ridge (after Baker, 1976, using our contact; Welsh, 1981, unpublished; respectively); queried in Springville quadrangle along the mountain front (compare to Baker, 1973). Present in Little and Big Baldy fault blocks.

Pogml **Oquirrh Formation, Granger Mountain Member, limestone unit** (Permian?, Wolfcampian? - Pennsylvanian, Virgilian) - Unit locally present at bottom of Granger Mountain Member; in Daniels Canyon area, consists of upper and lower ledge- and cliff-forming limestone intervals separated by slope-forming, yellowish-brown, calcareous siltstone interval with a few limestone interbeds; limestone is gray, medium to thick bedded, fossiliferous, and locally cherty; 0 to about 500 feet (0-150 m) thick (Biek and others, 2003).

Queried in Springville and Spanish Fork Peak quadrangles where Wolfcampian fusulinids present above basal limestone marker; 50 foot (15 m) thick marker in Springville quadrangle (see Baker, 1973) and could be several hundred feet thick in Spanish Fork Peak quadrangle (after Rawson, 1957, cross section and units 57 & 58, p. 27).

IPobm **Oquirrh Group, Bingham Mine Formation** (Upper Pennsylvanian, Virgilian-Missourian) - Calcareous sandstone, minor limestone, quartz sandstone, and shale; medium-gray to light-brown, calcareous sandstone typically weathers to light gray and grayish orange with pale red patches; contains medium-gray limestone interval with early Virgilian fusulinids; unit forms ledges and ledgy slopes; Missourian based on fusulinids (Welsh and James, 1961); queried on South Mountain because extensive fracturing makes identification uncertain; 5300 to 7311 feet (1600-2229 m) thick in Oquirrh Mountains (Welsh and James, 1961; Tooker and Roberts, 1970; Swenson, 1975), incomplete 4000 foot (1200 m) thickness in West Mountain (Clark, 2009), and correlative Wallsburg Ridge Member of Oquirrh is about 6400 feet (1950 m) thick to east in Wasatch Range.

IPowr **Oquirrh Formation, Wallsburg Ridge Member** (Pennsylvanian, Virgilian-Missourian) - Light-gray to yellowish-brown, thick-bedded, fine- to medium-grained quartzite and sandstone; feldspathic (orthoquartzite) to siliceous; quartzites commonly have conchoidal fracture; locally thinly laminated to cross-bedded; includes rare, silty and sandy, gray limestone interbeds; age from Baker (1976); about 3700 feet (1130 m) thick in Center Creek quadrangle (Biek and others, 2003), about 6400 feet (1950 m) thick to south in Wallsburg Ridge quadrangle (after Baker, 1976, using our contacts), 5280 feet thickness shown by Welsh (1981, unpublished), and possibly over 8000 feet (2450 m) thick to west in Wasatch Range (after Baker, 1947; 1973).

IPos **Oquirrh Formation, Shingle Mill Limestone Member** (Pennsylvanian, Missourian-Desmoinesian) - Dark-gray to black, thin-bedded limestone containing abundant black chert and locally abundant fossils; 200 to 450 feet (60-140 m) thick (Baker, 1972a); our map unit is the upper limestone of Welsh (1981, unpublished) that he showed as about 400 feet (120 m) thick; Biek and Lowe (2005) reported that conodont fauna in their Shingle Mill map unit indicate a Missourian age, rather than the Desmoinesian age reported by Baker (1976). Probable equivalent to Commercial and/or Jordan Limestone Members of the Bingham Mine Formation of Oquirrh Mountains/Bingham district (Welsh, 1981), but these limestones are not present on West Mountain (Clark, 2009).

IPobp, IPobl

Oquirrh Group, Butterfield Peaks Formation (Pennsylvanian, Desmoinesian-Atokan-Morrowan) - Interbedded, brown-weathering, fine-grained calcareous sandstone, medium-gray, fine-grained sandy limestone, minor orthoquartzite, and several limestone intervals (some mapped as IPobl); typically cyclically interbedded with several tens of feet of calcareous sandstone capped by gray limestone several feet thick; minor siltstone and shale interbeds form some poorly exposed slopes; unit typically forms ledgey to cliffy slopes; limestone intervals are locally fossiliferous with *Chaetetes* (coral) present in lower part of unit; fusulinid and conodont fossils provide some age control (Clark, 2009); queried on southwest end of South Mountain because extensive fracturing makes identification uncertain, though a single sample contained Atokan fusulinids; more than 4500 feet (1370 m) thick, top not exposed, in Lake Mountains (Biek, 2004) and more than 7300 feet (2200 m) thick, base not exposed, in West Mountain (Clark, 2009); complete thickness 9070 feet (2765 m) in Oquirrh Mountains (Tooker and Roberts, 1970); lithologically and near-age correlative with Bear Canyon Member of Oquirrh Formation. Limestone units (IPobl), locally mapped to show structural geology, commonly contain spherical or irregularly shaped, black chert; about 40 to 300 feet (12-90 m) thick in Lake Mountains and West Mountain (see Biek, 2004; Biek and others, 2009; Clark, 2009).

IPobc **Oquirrh Formation, Bear Canyon Member** (Pennsylvanian, Desmoinesian-Atokan) - Gray to tan, limy to quartzitic sandstone with interbedded gray to black, thin- to thick-bedded, cherty to locally sandy limestone; about 4250 to 8350 feet (1300-2550 m) thick in map area (after Baker, 1947, 1972a, 1976), thickening northward and eastward; Welsh (1981, unpublished) has 8650 feet (2635 m) below the upper limestone in his type section in the Aspen Grove and Wallsburg Ridge quadrangles, but the section is faulted and he reported only about 4500 feet (1400 m) in a reference section in the Charleston quadrangle; age from Baker (1976); latest Morrowan conodonts reported in lowest part of roughly equivalent strata in Bridal Veil Falls quadrangle (Shoore, 2005), but sample location uncertain. Strata at top of Mount Timpanogos may include some Shingle Mill Limestone and Wallsburg Ridge Members of Oquirrh (see Konopka, 1999).

IPowc **Oquirrh Group, West Canyon Limestone** (Pennsylvanian, Morrowan) - Gray, sandy to fossiliferous limestone; fossils include crinoid columnals, brachipods, bryozoans, and rugose corals; lower part forms ledges and upper part contains prominent cliff-forming limestone beds with irregular chert nodules and beds; medial calcareous sandstone; Webster (1984) reported Early Pennsylvanian conodonts from the Lake and Oquirrh Mountains; latest Chesterian (Late Mississippian) conodonts reported in Oquirrh Mountains (see Davis and others, 1994), but these conodonts are actually from the uppermost Manning Canyon Shale; Biek (2004) measured 1025 feet (313 m) of West Canyon in the Lake Mountains; lithologically and near-age correlative with Bridal Veil Limestone Member of Oquirrh Formation.

IPobv **Oquirrh Formation, Bridal Veil Limestone Member** (Pennsylvanian, Atokan? and Morrowan) - Medium-gray to black, thin- to thick-bedded limestone with local beds of quartzite; limestone contains much brown to black chert and some abundantly fossiliferous beds; measured thickness 1245 feet (380 m) (Baker, 1972a); contains Morrowan conodonts in Charleston quadrangle (Biek and Lowe, 2005); see roughly equivalent West Canyon Limestone description above for comment on Mississippian age.

Mmc **Manning Canyon Shale** (lower Pennsylvanian? and upper Mississippian, Chesterian) - Black to brown shale with numerous thin beds of light-brown-weathering, gray, fine-grained, shaly sandstone, some lenses or beds of rusty-weathering grit, and one or more thick beds of gray to black, cherty limestone; at least in west contains some beds of light-brown quartzite; shale is carbonaceous with occasional nodules of marcasite; measured thickness in Bridal Veil Falls quadrangle is 1650 feet (500 m) (Baker, 1972a); 1176 feet (359 m) measured thickness in Lake Mountains (Biek and others, 2009); age from macro-fossils (for example, cephalopod *Eumorphoceras bisulcatum*) reported in Baker (1972a) that are Chesterian in age (see Welsh and Bissell, 1979); Pennsylvanian age considered unlikely since definitive brachiopod, *Dictyoclostus hermosanus*, from Baker (1972a) is Atokan (Welsh and Bissell, 1979), so likely misidentified. The Manning Canyon is a zone of detachment/decollement, such that the unit is attenuated and faulted out along regional scale thrust faults (see for example Biek and others, 2003).

Mgb **Great Blue Limestone, undivided** (Upper Mississippian, Chesterian?-Meramecian) - Dark-gray to nearly black, light- to medium-gray-weathering, thin- and regularly bedded limestone and shaly limestone with interbedded black and brown shale beds up to 50 feet (15 m) thick, and, near base, scattered thin beds of olive-brown-weathering, dark-gray, fine-grained quartzite; series age after Chamberlain (1981); measured thickness about 2800 feet (850 m) in Rock Canyon, Bridal Veil Falls quadrangle (Baker, 1947, 1972a; after Chamberlain, 1981); attenuated by faulting south of Slide Canyon. Black shale is prominent basal part in Wasatch Range and is described and shown as 100 to 700 feet (30-215 m) thick by Baker (1947), Crittenden (1959), and Chamberlain (1981); this black shale can be attenuated or faulted out, possibly resulting in the thickness variation. In west part of map area divided where possible into upper and lower parts:

Mgbu **Great Blue Limestone, upper limestone member** - Bluish gray, medium- to very thick bedded limestone, locally cherty and fossiliferous, with interbedded shales in lower part; 2100 feet (640 m) thick in Lake Mountains (Biek, 2004; Biek and others, 2009).

Mgbsl **Great Blue Limestone, Long Trail Shale and lower limestone members** - Long Trail is dark shale and thin-bedded limestone that erodes to saddles; lower member is medium gray, fossiliferous limestone that is thinner bedded and argillaceous with some shale in upper part; 390 feet (120 m) thick in Lake Mountains (Biek, 2004; Biek and others, 2009).

Mh **Humbug Formation** (Upper Mississippian) - Light- to dark-gray, cherty limestone and some dolomite interbedded with light-gray to buff, brown-weathering, limy to quartzitic sandstone, which causes characteristic brown and gray bands in outcrops; measured thickness 520 feet (160 m) in Rock Canyon, Bridal Veil Falls quadrangle (Baker, 1972a); Welsh (in Clark, 2009) measured 785 feet (240 m) on West Mountain.

Mde **Deseret Limestone** (Upper and Lower Mississippian) - Interbedded, thick-bedded limestone and dolomite with distinctive light- and dark-gray banded outcrops; fossil crinoids and corals common; black chert occurs as thin layers, blebs, and irregular masses in most beds and is locally very abundant; about 585 feet (175 m) thick in Wasatch Range (Baker, 1964b); Welsh (in Clark, 2009) measured 765 feet (235 m) on West Mountain, and from 700 to 1000 feet (210-300 m) in Lake Mountains area (Biek and others, 2009). The Delle Phosphatic Member is present at Rock Canyon, but is likely thinner than shown by Sandberg and Gutschick (1979); Delle also present in Lake Mountains (Biek, 2004; Biek and others, 2009).

Mgf **Gardison and Fitchville Formations, undivided** - Used in east part of map area.

Mg **Gardison Limestone** (Lower Mississippian) - Dark-gray, "stair-step"-forming, mostly thin-bedded limestone with scattered abundant light-brown to black chert; about 600 feet (180 m) thick in Timpanogos Cave quadrangle (Baker, 1947; Baker and Crittenden, 1961); 900 feet (275 m) thickness in Rock Canyon (Baker, 1964b) likely includes Deseret strata; similar thickness in Spanish Fork quadrangle (Solomon and others, 2007), but Delle at upper contact not recognized; Welsh (in Clark, 2009) measured 620 feet (190 m) on West Mountain. Mapped separately west of Utah Lake where Pinyon Peak is present and is mapped with Fitchville (MDfp). Fitchville and Pinyon Peak Formations absent at unconformity in Spanish Fork quadrangle (Solomon and others, 2007).

Fitchville Dolomite (Lower Mississippian and Upper Devonian) - Medium- to light-gray, cliff-forming dolomite with numerous small vugs; lacks chert, which is atypical for Mississippian units; interbedded limestone in upper part; buff to gray, locally conglomeratic, coarse-grained sandstone or grit comprise basal bed 1 to 20 feet (0.3-6 m) thick; 100 to 265 feet (30-80 m) thick (Baker, 1973); Devonian age of dolomite at Rock Canyon from Sandberg and Gutschick (1979, p. 114). Basal clastic bed may unconformably underlie dolomite.

MDfp **Fitchville and Pinyon Peak Formations, undivided** (Lower Mississippian and Upper Devonian) - **Fitchville** is light-blue-gray limestone and light-gray dolomite with crinoids, brachiopods and corals. Devonian **Pinyon Peak Limestone** is medium- to dark-gray dolomite with crinoid, gastropod, and silicified coral fossils; may not be present in Wasatch Range or Devonian strata may be mapped with Fitchville; unconformably overlies Cambrian strata. Total thickness 300 feet (90 m) in West Mountain (Welsh, in Clark, 2009) and more than 300 feet (90 m), base not exposed, in Lake Mountains (Biek, 2004).

Cote **Opex through Teutonic Formations** (Upper and Middle Cambrian) - Mapped in southern West Mountain and includes the Opex Formation?, Cole Canyon Dolomite, Bluebird Dolomite, Herkimer Limestone, Dagmar Dolomite, and Teutonic Limestone; gray to mottled dolomite and limestone, locally with twiggy bodies and pisolites; limestone commonly has discontinuous, tan siltstone bands and partings; average aggregate thickness of 1725 feet (525 m) (see Clark, 2009 for details).

Ccte? **Cole Canyon through Teutonic Formations?** (Upper and Middle Cambrian) - Gray to mottled dolomite, locally with twiggy bodies and pisolites; located along Picayune Canyon fault zone in Spanish Fork quadrangle and commonly brecciated, fractured, and dolomitized (Ajax/Opex missing?); includes all or some of the Cole Canyon Dolomite, Bluebird Dolomite, Herkimer Limestone, Dagmar Dolomite, and Teutonic Limestone; 1400 feet (400 m) thick (Cu of Solomon and others, 2007).

Cmo **Maxfield and Ophir Formations, undivided** - Used where geology is complex along west flank of Wasatch Range.

Cm **Maxfield Limestone** (Middle Cambrian) - Mainly light- to dark-gray, thin-bedded limestone with yellow-brown to grayish-yellow mottling, and with interbedded gray to white dolomite and oolitic or pisolitic limestone; unconformably overlain by Fitchville and absent in northern Timpanogos Cave quadrangle (Baker and Crittenden, 1961); 0 to less than 850 feet (0 to <260 m) thick (Baker, 1973); 595 feet (180 m) thick in Bridal Veil Falls quadrangle (Baker, 1972a).

Co **Ophir Formation** (Middle Cambrian) - Olive-green, slope-forming, micaceous shale with thin beds of greenish sandstone and a zone of thin beds of yellow to brown-mottled shaly limestone in upper part; contact with Maxfield is gradational and may not have been picked consistently; about 100 to 290 feet (30-90 m) thick in Springville and Bridal Veil Falls quadrangles (Baker, 1972a, 1973). Reportedly 510 feet (155 m) thick in American Fork Canyon with characteristic three units: upper shale/micaceous sandstone [phyllite] (170 feet [50 m] thick), middle limestone (100 feet [30 m] thick), and lower shale and sandstone (250 feet [75 m] thick) (Baker and Crittenden, 1961; Baker, 1964b). Measured thickness 307 feet (94 m) in southern West Mountain (Elison, 1952; Schindler, 1952; Swanson, 1952).

Ct **Tintic Quartzite** (Middle and Lower? Cambrian) - Light-brown weathering, cliff- and ledge-forming, off-white to tan quartzite with quartz-pebble conglomeratic beds in lower 200 feet (60 m) and boulders of quartz 1 foot (0.3 m) or more in diameter near basal unconformity; interbedded greenish quartzite and phyllite in top 90 feet (30 m), forming gradational contact with overlying Ophir; near Provo, thin (0-80 feet [0-24 m]) diabase flow(?) locally near base (Abbott, 1951); measured thickness 1170 feet (355 m) in Slate Canyon, Springville quadrangle (Baker, 1973); more than 700 feet (200 m) thick in West Mountain, base not exposed (Clark, 2009).

Zm **Mutual Formation** (Neoproterozoic) - Rusty to red-purple quartzite, grit, and pebble to boulder conglomerate with minor grayish-red or greenish shale; clasts are schist, gneiss, limestone, and tillite; characteristic grit contains same lithologies, as well as black shale, quartz, and feldspar; 0 to 1300 feet (400 m) thick and thinning to east; unconformably overlies Mineral Fork Tillite (Baker and Crittenden, 1961); only exposed in Timpanogos Cave quadrangle.

Zmf **Mineral Fork Tillite** (Neoproterozoic) - Gray to brown and olive drab, dark-brown- to black-weathering, unstratified and poorly sorted, micaceous siltstone with scattered boulders of dolomite, quartzite, sandstone, and altered (green) igneous rock up to 1 foot (0.3 m) in diameter; unconformity at base; complete thickness 250 to 300 feet (75-90 m) in American Fork Canyon and may be much thicker (1000 feet [300 m]) to north in map area (Baker and Crittenden, 1961), thinning southward to nothing near Slate Canyon (Baker, 1973).

Zbc **Big Cottonwood Formation** (Neoproterozoic and Mesoproterozoic?) - Purple to maroon, brown, and pinkish-gray, fine-grained to conglomeratic quartzite with interbedded gray, green, brown, and purple micaceous quartzite and phyllite, and purple, red, and maroon slate (argillite); exposed partial thickness about 400 feet (120 m) near Deer Creek Reservoir (Biek and Lowe, 2005) and 1350 feet (410 m) east of Provo (Baker, 1973); age from data in Dehler and others (2010).

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(Numbers refer to figure 1, plate 2 - Index to sources of geologic mapping;
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APPENDIX C

HYDROLOGIC
DATA

NOAA 2nd Quartile 50 Percent 100-Yr 24-Hour*

Time (hours)	Incremental Precipitation (inches)
0	0.000
2	0.199
4	0.417
6	0.686
8	1.047
10	1.487
12	1.904
14	2.204
16	2.400
18	2.548
20	2.671
22	2.755
24	2.800

*From Figure A.1.8 of NOAA Atlas 14, Volume 1

Farmer-Fletcher Modified 3-hour Storm Distribution

Time (min)	Incremental Precipitation (inches)
0	0.000
5	0.011
10	0.014
15	0.016
20	0.018
25	0.023
30	0.088
35	0.251
40	0.198
45	0.138
50	0.088
55	0.053
60	0.041
65	0.009
70	0.009
75	0.009
80	0.009
85	0.009
90	0.009
95	0.009
100	0.009
105	0.009
110	0.009
115	0.009
120	0.009
125	0.009
130	0.009
135	0.009
140	0.009
145	0.009
150	0.009
155	0.009
160	0.009
165	0.009
170	0.009
175	0.009
180	0.009
Total	1.158

Location information:

Name: Payson, Utah, USA*

Latitude: 40.0250°

Longitude: -111.7222°

Elevation: 4830.59 ft *
*

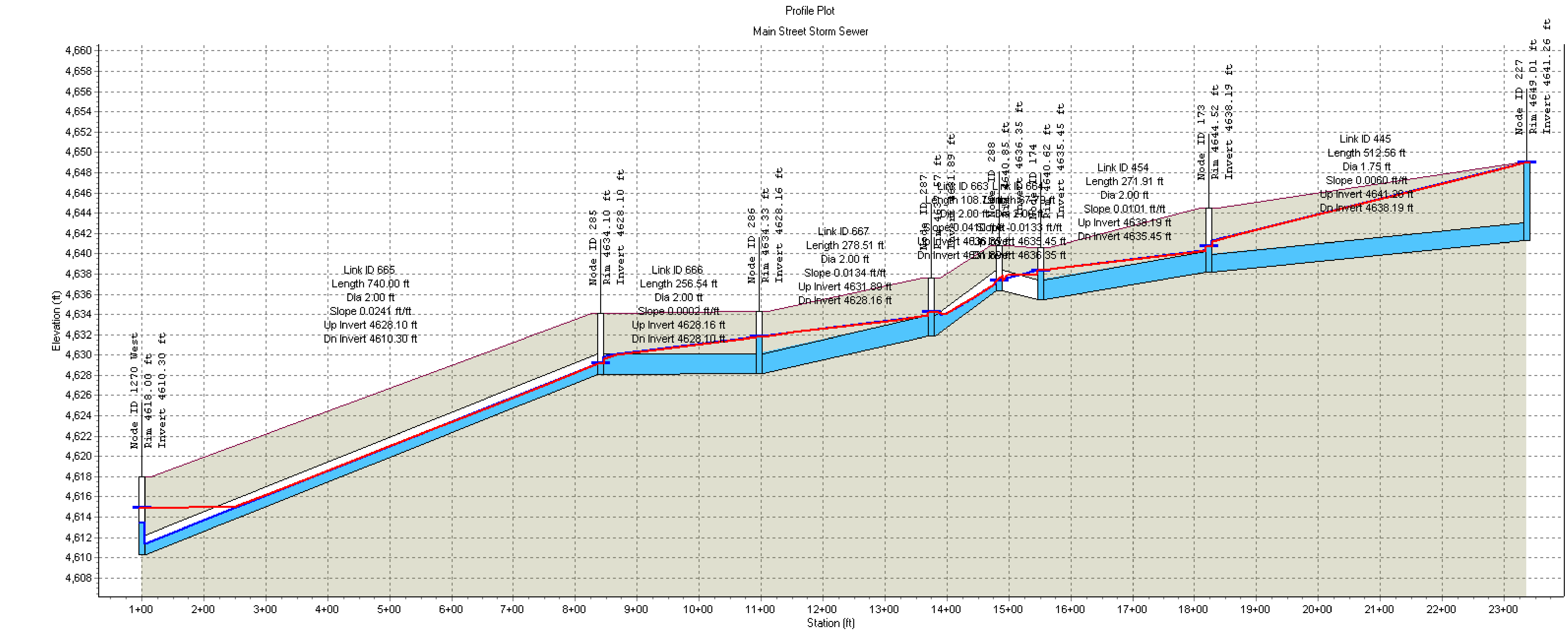
PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	**0.127**(0.110-0.150)	**0.162**(0.141-0.193)	**0.225**(0.193-0.267)	**0.280**(0.238-0.333)	**0.366**(0.304-0.438)	**0.444**(0.360-0.533)	**0.534**(0.422-0.644)	**0.637**(0.488-0.778)	**0.802**(0.586-0.997)	**0.949**(0.668-1.20)
10-min	**0.194**(0.168-0.229)	**0.247**(0.214-0.294)	**0.342**(0.294-0.406)	**0.427**(0.362-0.507)	**0.557**(0.462-0.666)	**0.675**(0.548-0.810)	**0.812**(0.642-0.980)	**0.969**(0.743-1.18)	**1.22**(0.892-1.52)	**1.44**(1.02-1.83)
15-min	**0.240**(0.208-0.284)	**0.306**(0.266-0.364)	**0.424**(0.365-0.503)	**0.529**(0.450-0.629)	**0.690**(0.573-0.825)	**0.837**(0.679-1.00)	**1.01**(0.796-1.22)	**1.20**(0.921-1.47)	**1.51**(1.11-1.88)	**1.79**(1.26-2.27)
30-min	**0.323**(0.280-0.382)	**0.412**(0.358-0.490)	**0.571**(0.491-0.677)	**0.712**(0.605-0.847)	**0.930**(0.771-1.11)	**1.13**(0.915-1.35)	**1.36**(1.07-1.64)	**1.62**(1.24-1.98)	**2.04**(1.49-2.53)	**2.41**(1.70-3.05)
60-min	**0.399**(0.347-0.472)	**0.510**(0.443-0.607)	**0.707**(0.608-0.838)	**0.881**(0.749-1.05)	**1.15**(0.954-1.38)	**1.40**(1.13-1.67)	**1.68**(1.33-2.03)	**2.00**(1.54-2.45)	**2.52**(1.84-3.13)	**2.98**(2.10-3.78)
2-hr	**0.499**(0.441-0.580)	**0.629**(0.553-0.729)	**0.832**(0.728-0.966)	**1.01**(0.879-1.18)	**1.31**(1.11-1.53)	**1.57**(1.30-1.84)	**1.87**(1.51-2.22)	**2.22**(1.73-2.66)	**2.77**(2.07-3.39)	**3.27**(2.35-4.09)
3-hr	**0.577**(0.517-0.659)	**0.720**(0.643-0.822)	**0.920**(0.820-1.05)	**1.10**(0.973-1.26)	**1.39**(1.20-1.59)	**1.63**(1.39-1.89)	**1.93**(1.60-2.25)	**2.27**(1.84-2.69)	**2.83**(2.19-3.41)	**3.33**(2.49-4.10)
6-hr	**0.750**(0.681-0.838)	**0.925**(0.838-1.03)	**1.14**(1.02-1.27)	**1.32**(1.19-1.48)	**1.59**(1.40-1.79)	**1.82**(1.59-2.06)	**2.08**(1.79-2.38)	**2.39**(2.02-2.77)	**2.93**(2.40-3.46)	**3.41**(2.73-4.14)
12-hr	**0.961**(0.877-1.06)	**1.18**(1.08-1.31)	**1.43**(1.30-1.58)	**1.64**(1.48-1.82)	**1.94**(1.74-2.15)	**2.17**(1.92-2.43)	**2.42**(2.12-2.73)	**2.71**(2.34-3.10)	**3.19**(2.69-3.70)	**3.60**(2.98-4.25)
24-hr	**1.18**(1.10-1.27)	**1.46**(1.36-1.57)	**1.75**(1.63-1.88)	**1.99**(1.85-2.13)	**2.31**(2.14-2.48)	**2.55**(2.36-2.75)	**2.80**(2.58-3.02)	**3.05**(2.79-3.29)	**3.38**(3.07-3.74)	**3.63**(3.27-4.29)
2-day	**1.32**(1.24-1.42)	**1.62**(1.51-1.75)	**1.96**(1.82-2.11)	**2.24**(2.08-2.40)	**2.62**(2.43-2.82)	**2.92**(2.69-3.14)	**3.23**(2.96-3.48)	**3.55**(3.24-3.83)	**3.99**(3.59-4.33)	**4.32**(3.86-4.72)
3-day	**1.46**(1.36-1.57)	**1.79**(1.67-1.94)	**2.17**(2.02-2.35)	**2.49**(2.31-2.69)	**2.94**(2.72-3.17)	**3.30**(3.03-3.56)	**3.66**(3.35-3.96)	**4.05**(3.67-4.39)	**4.57**(4.10-4.98)	**4.99**(4.43-5.46)
4-day	**1.59**(1.47-1.72)	**1.96**(1.82-2.13)	**2.39**(2.22-2.59)	**2.75**(2.55-2.98)	**3.26**(3.01-3.53)	**3.67**(3.36-3.98)	**4.10**(3.73-4.45)	**4.54**(4.10-4.94)	**5.16**(4.61-5.63)	**5.65**(5.00-6.20)
7-day	**1.85**(1.73-2.00)	**2.28**(2.13-2.46)	**2.77**(2.58-2.99)	**3.17**(2.95-3.41)	**3.73**(3.45-4.01)	**4.16**(3.83-4.47)	**4.61**(4.22-4.96)	**5.06**(4.61-5.47)	**5.68**(5.12-6.16)	**6.16**(5.51-6.71)
10-day	**2.10**(1.96-2.25)	**2.58**(2.42-2.76)	**3.11**(2.91-3.33)	**3.54**(3.31-3.78)	**4.11**(3.83-4.39)	**4.55**(4.22-4.87)	**5.00**(4.61-5.35)	**5.44**(5.00-5.85)	**6.03**(5.49-6.52)	**6.49**(5.86-7.03)
20-day	**2.81**(2.63-3.00)	**3.47**(3.24-3.71)	**4.14**(3.88-4.43)	**4.67**(4.37-4.99)	**5.35**(4.99-5.71)	**5.86**(5.45-6.25)	**6.35**(5.90-6.79)	**6.84**(6.33-7.32)	**7.45**(6.86-8.02)	**7.90**(7.24-8.53)
30-day	**3.42**(3.20-3.66)	**4.20**(3.94-4.51)	**5.03**(4.70-5.39)	**5.69**(5.32-6.10)	**6.56**(6.12-7.03)	**7.22**(6.72-7.75)	**7.89**(7.30-8.47)	**8.54**(7.86-9.20)	**9.40**(8.59-10.2)	**10.0**(9.12-10.9)
45-day	**4.26**(3.99-4.55)	**5.23**(4.89-5.60)	**6.20**(5.81-6.63)	**6.96**(6.51-7.45)	**7.95**(7.43-8.51)	**8.68**(8.09-9.30)	**9.41**(8.73-10.1)	**10.1**(9.34-10.9)	**11.0**(10.1-11.9)	**11.6**(10.6-12.6)
60-day	**5.14**(4.81-5.49)	**6.32**(5.91-6.76)	**7.48**(7.00-8.00)	**8.37**(7.82-8.95)	**9.51**(8.86-10.2)	**10.3**(9.60-11.1)	**11.1**(10.3-11.9)	**11.9**(11.0-12.8)	**12.9**(11.8-13.8)	**13.6**(12.4-14.6)

APPENDIX D

PROFILES OF STORM DRAIN TRUNKLINES

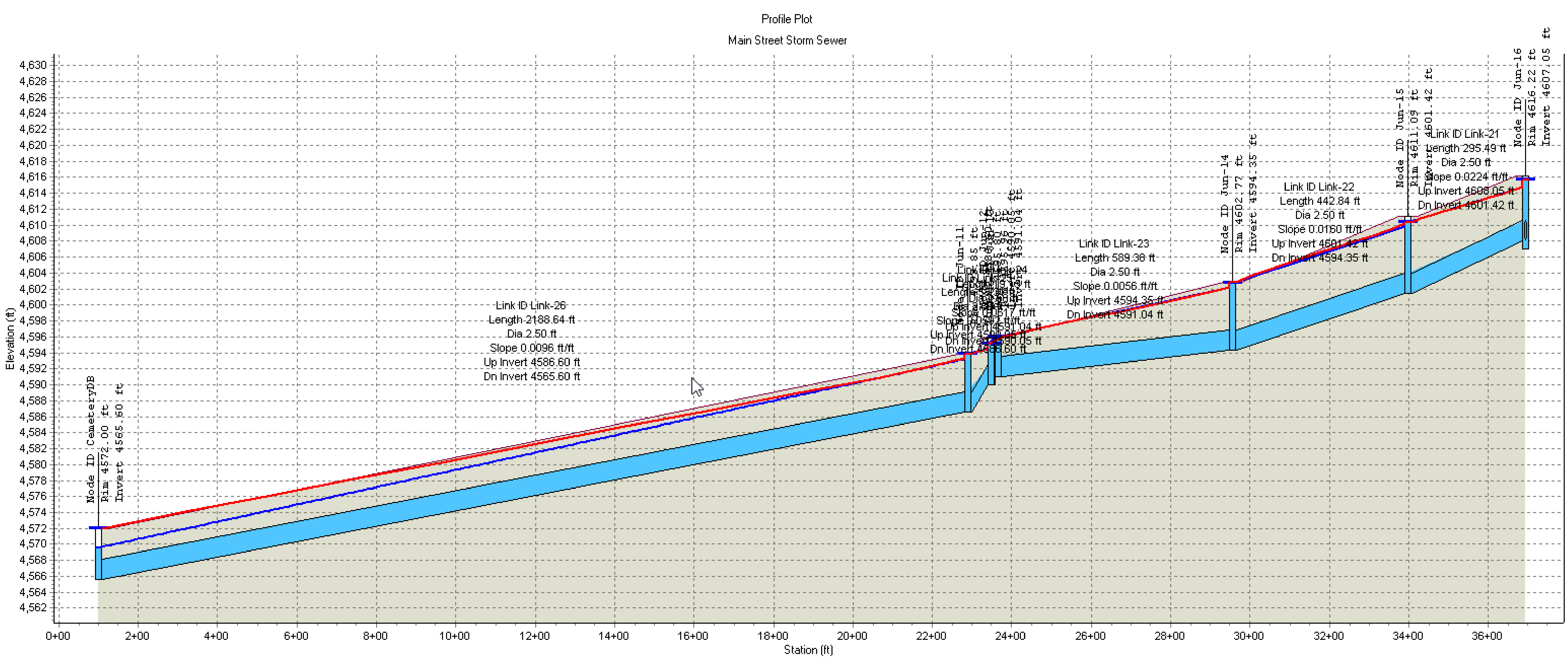
1270 West / 800 South Trunkline Profile



Node ID:	1270 West	285	286	287	288	174	173	227
Rim (ft):	4618.00	4634.10	4634.33	4637.57	4640.85	4640.62	4644.52	4649.01
Invert (ft):	4610.30	4628.10	4628.16	4631.89	4636.35	4635.45	4638.19	4641.26
Min Pipe Cover (ft):		4.00	4.17	3.68	2.50	3.17	4.33	6.00
Max HGL (ft):	4614.92	4629.17	4631.84	4634.21	4637.36	4638.49	4641.56	4649.01

Link ID:	665	666	667	663	664	454	445
Length (ft):	740.00	256.54	278.51	108.79	67.79	271.91	512.56
Dia (ft):	2.00	2.00	2.00	2.00	2.00	2.00	1.75
Slope (ft/ft):	0.0241	0.0002	0.0134	0.0410	-0.0133	0.0101	0.0060
Up Invert (ft):	4628.10	4628.16	4631.89	4636.35	4635.45	4638.19	4641.26
Dn Invert (ft):	4610.30	4628.10	4628.16	4631.89	4636.35	4635.45	4638.19
Max Q (cfs):	19.57	19.59	19.59	19.69	19.59	19.58	19.58
Max Vel (ft/s):	7.95	7.59	6.27	10.17	7.82	6.23	8.14
Max Depth (ft):	1.53	1.53	2.00	1.50	1.50	2.00	1.75

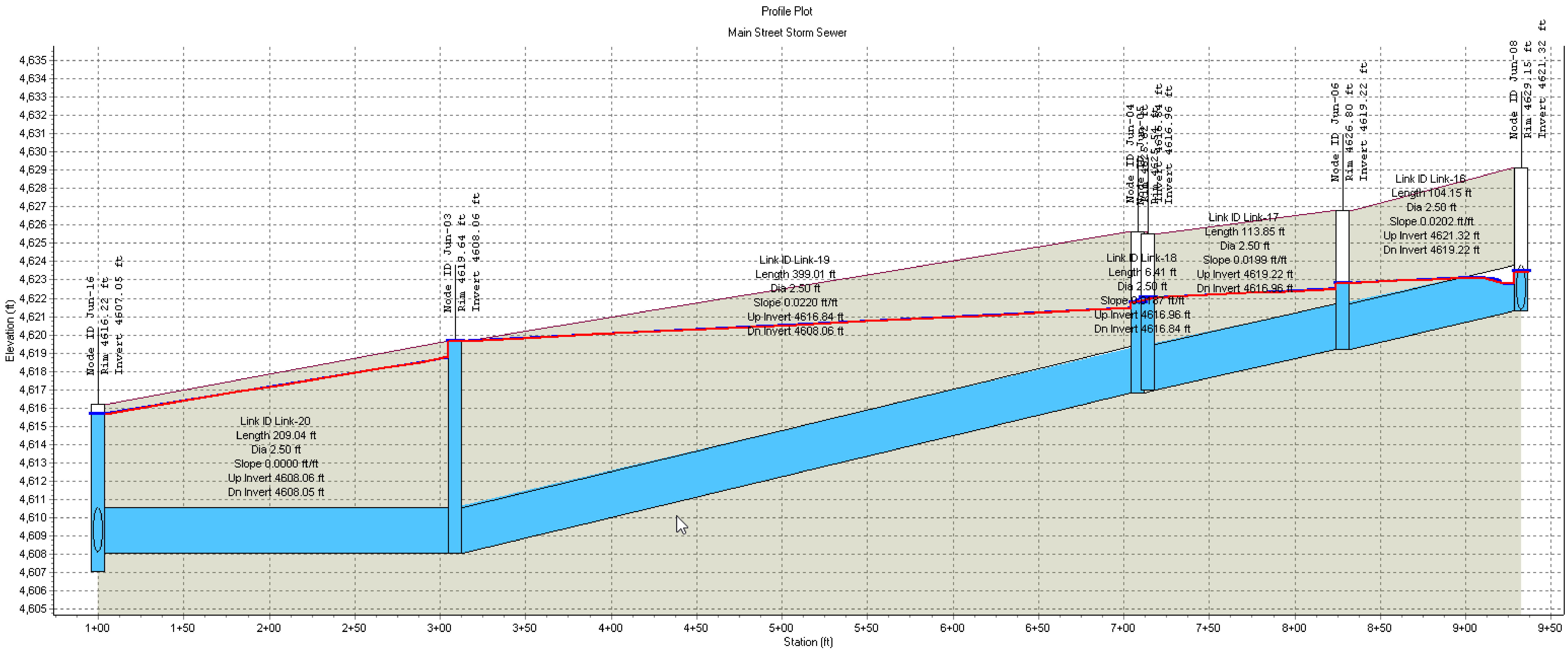
900 East / Cemetery Trunkline Profile



Node ID:	CemeteryDB		Jun-11/Jun-12/Jun-13 [illegible]	Jun-14	Jun-15	Jun-16
Rim (ft):	4572.00		[illegible]	4602.77	4611.09	4616.22
Invert (ft):	4565.60		[illegible]	4594.35	4601.42	4607.05
Min Pipe Cover (ft):			[illegible]	5.92	7.17	5.67
Max HGL (ft):	4572.00		[illegible]	4602.77	4611.09	4616.22

Link ID:	Link-26	Link-25/Link-24 [illegible]	Link-23	Link-22	Link-21
Length (ft):	2188.64	[illegible]	589.38	442.84	295.49
Dia (ft):	2.50	2.50 / 2.50	2.50	2.50	2.50
Slope (ft/ft):	0.0096	[illegible]	0.0056	0.0160	0.0224
Up Invert (ft):	4586.60	[illegible]	4594.35	4601.42	4608.05
Dn Invert (ft):	4565.60	[illegible]	4591.04	4594.35	4601.42
Max Q (cfs):	45.70	[illegible]	42.19	50.57	50.58
Max Vel (ft/s):	10.57	[illegible]	8.60	10.30	11.78
Max Depth (ft):	2.50	2.50 / 2.50	2.50	2.50	2.50

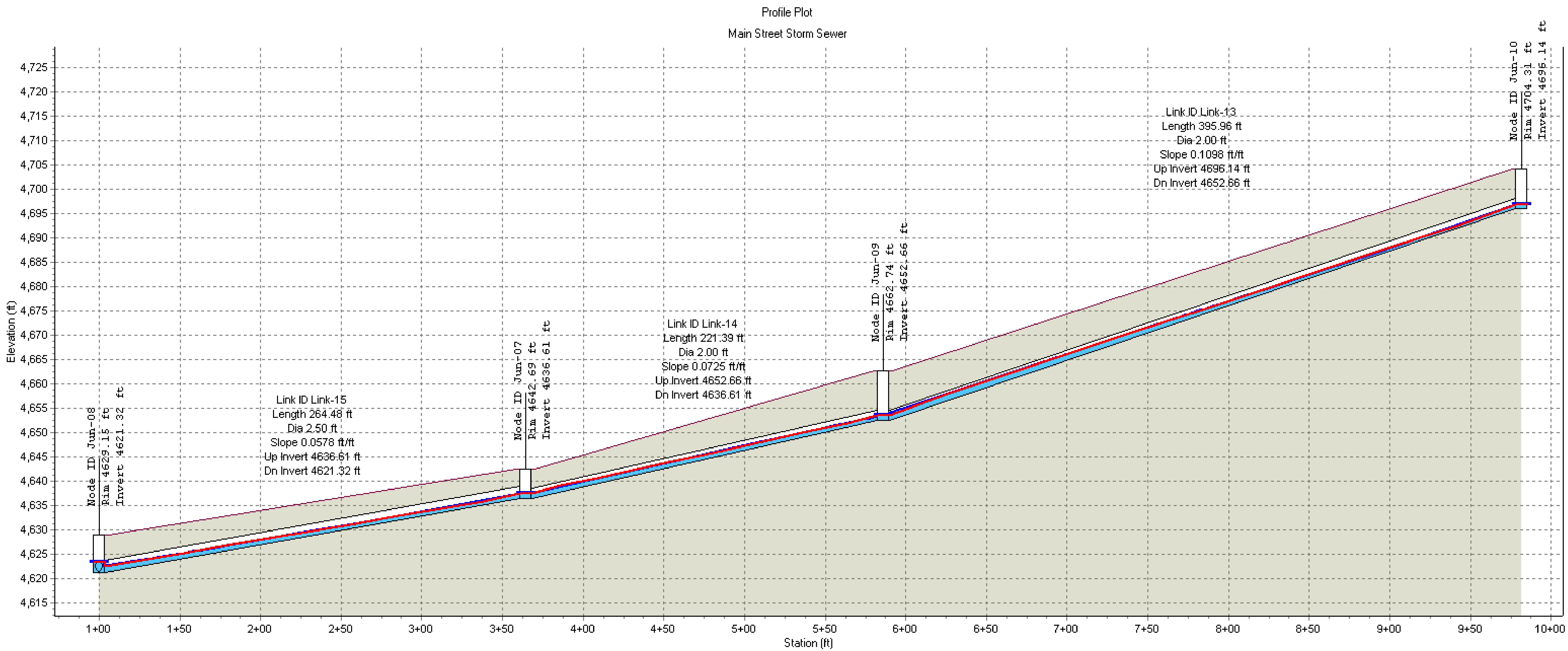
900 East / Cemetery Trunkline Profile



Node ID:	Jun-16	Jun-03		[illegible]	Jun-06	Jun-08
Rim (ft):	4616.22	4619.64		[illegible]	4626.80	4629.15
Invert (ft):	4607.05	4608.06		[illegible]	4619.22	4621.32
Min Pipe Cover (ft):	5.67	0.00		[illegible]	5.08	5.33
Max HGL (ft):	4616.22	4619.64		[illegible]	4622.89	4623.53

Link ID:	Link-20	Link-19	Link-18	Link-17	Link-16
Length (ft):	209.04	399.01	6.41	113.85	104.15
Dia (ft):	2.50	2.50	2.50	2.50	2.50
Slope (ft/ft):	0.0000	0.0220	0.0187	0.0199	0.0202
Up Invert (ft):	4608.06	4616.84	4616.96	4619.22	4621.32
Dn Invert (ft):	4608.05	4608.06	4616.84	4616.96	4619.22
Max Q (cfs):	50.57	28.30	28.30	28.30	28.30
Max Vel (ft/s):	10.30	6.17	9.12	8.41	9.82
Max Depth (ft):	2.50	2.50	2.50	2.50	2.32

900 East / Cemetery Trunkline Profile

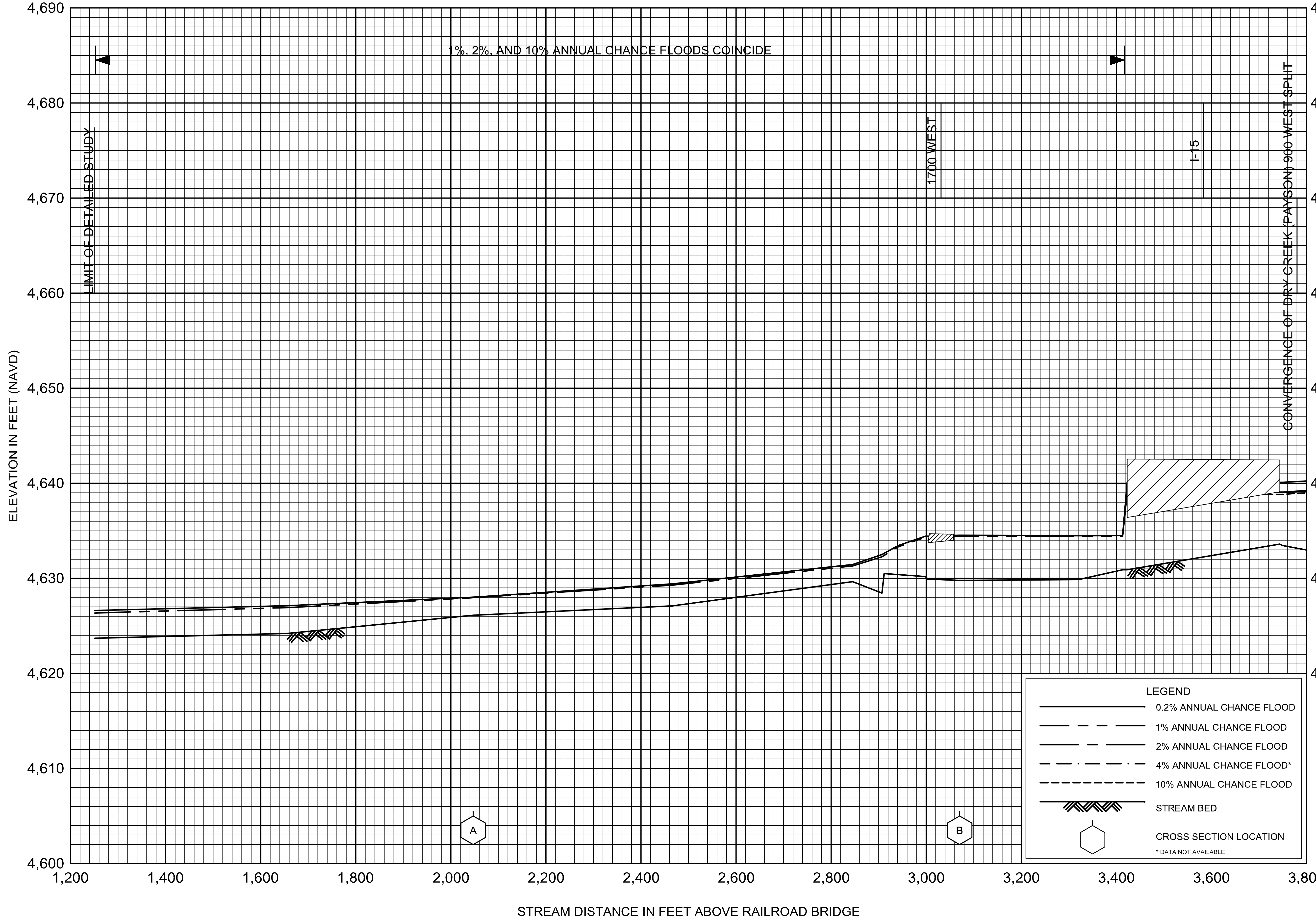


Node ID:	Jun-08	Jun-07	Jun-09	Jun-10
Rim (ft):	4629.15	4642.69	4662.74	4704.31
Invert (ft):	4621.32	4636.61	4652.66	4696.14
Min Pipe Cover (ft):	5.33	3.58	8.08	0.00
Max HGL (ft):	4623.53	4637.53	4653.69	4697.00

Link ID:	Link-15	Link-14	Link-13
Length (ft):	264.48	221.39	395.96
Dia (ft):	2.50	2.00	2.00
Slope (ft/ft):	0.0578	0.0725	0.1098
Up Invert (ft):	4636.61	4652.66	4696.14
Dn Invert (ft):	4621.32	4636.61	4652.66
Max Q (cfs):	28.58	28.59	28.60
Max Vel (ft/s):	12.49	18.79	19.64
Max Depth (ft):	1.52	0.97	0.94

APPENDIX E

FEMA HYDRAULIC PROFILE OF DRY CREEK



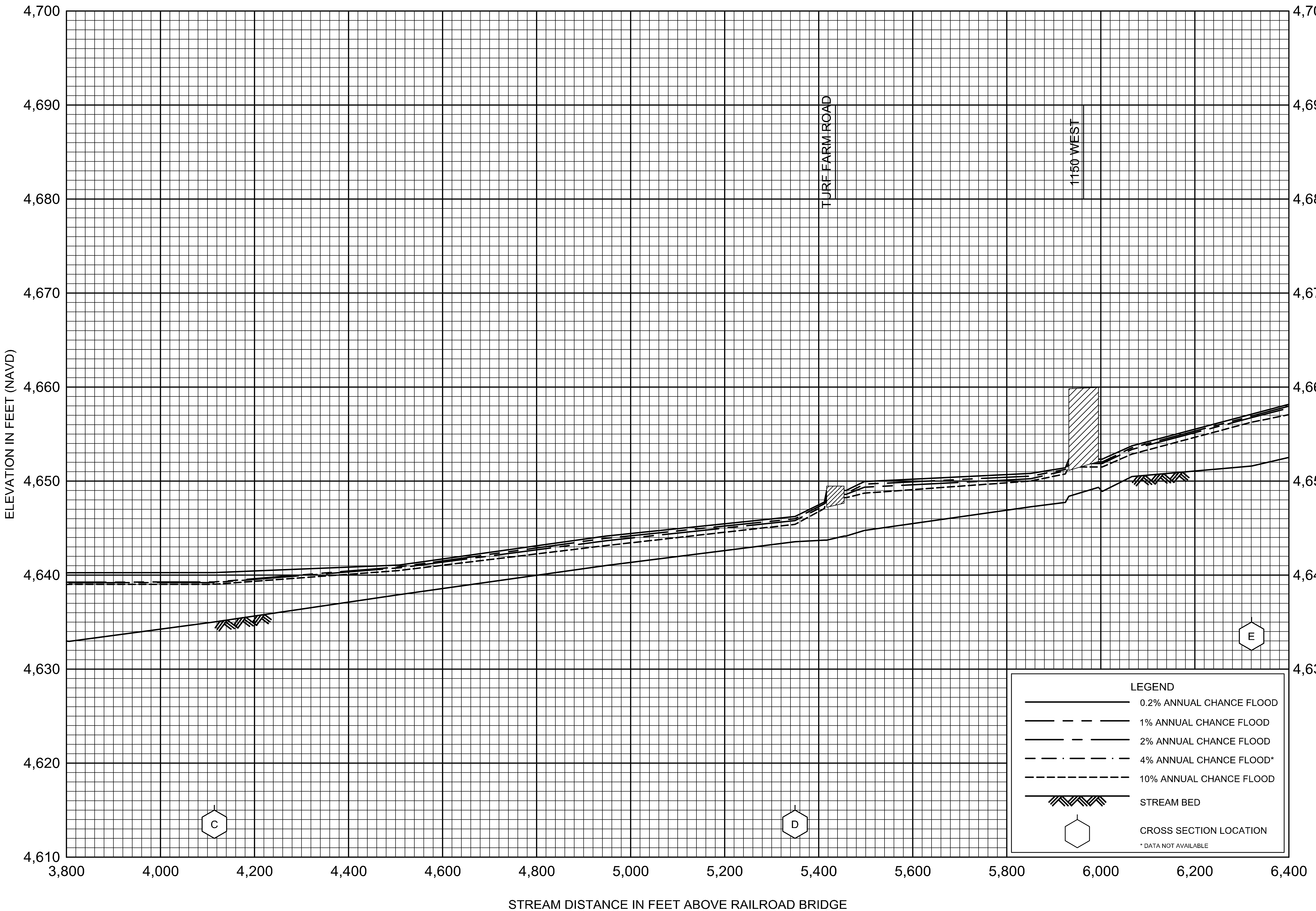
FLOOD PROFILES

DRY CREEK (PAYSON)

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS



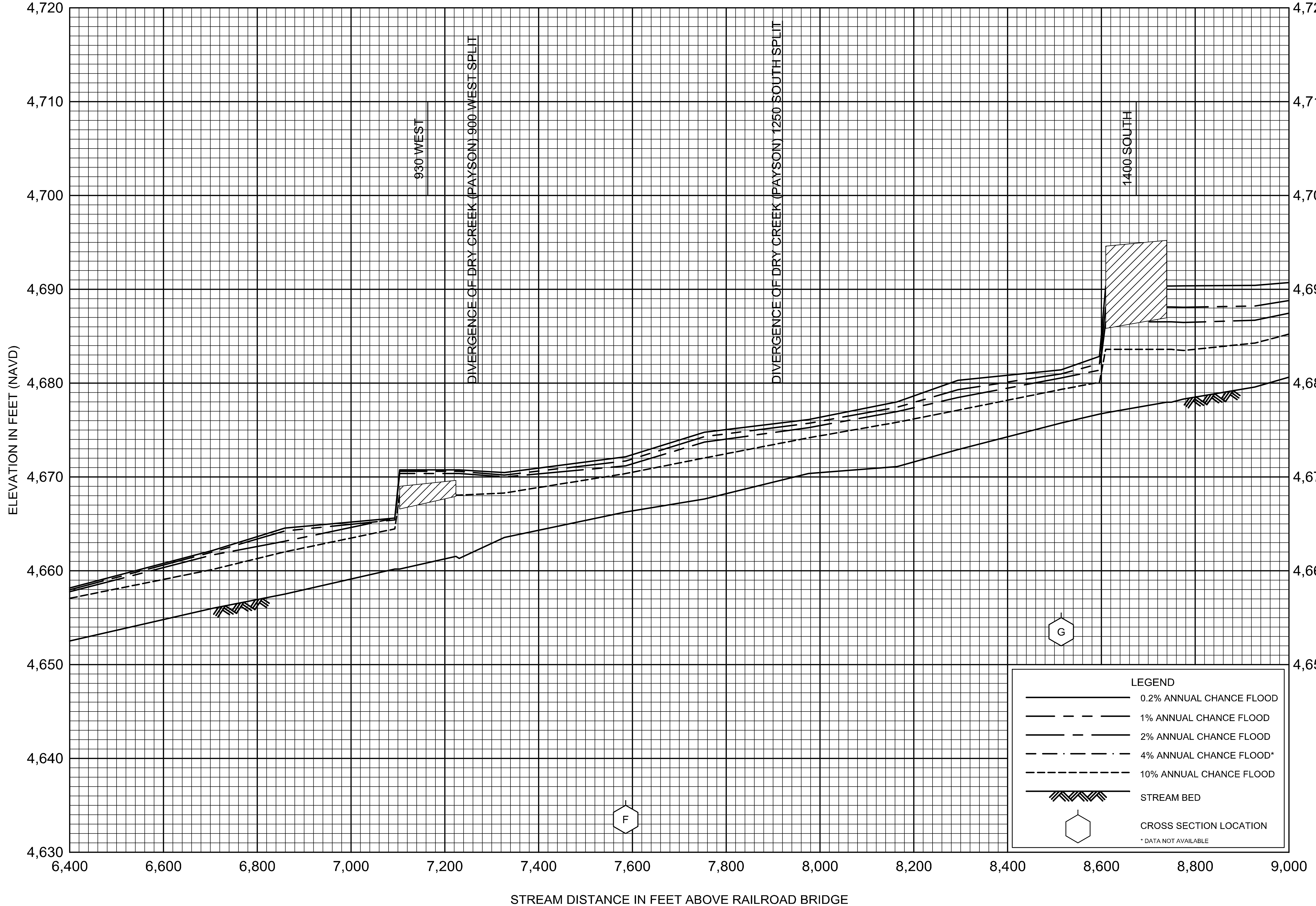
FLOOD PROFILES

DRY CREEK (PAYSON)

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS



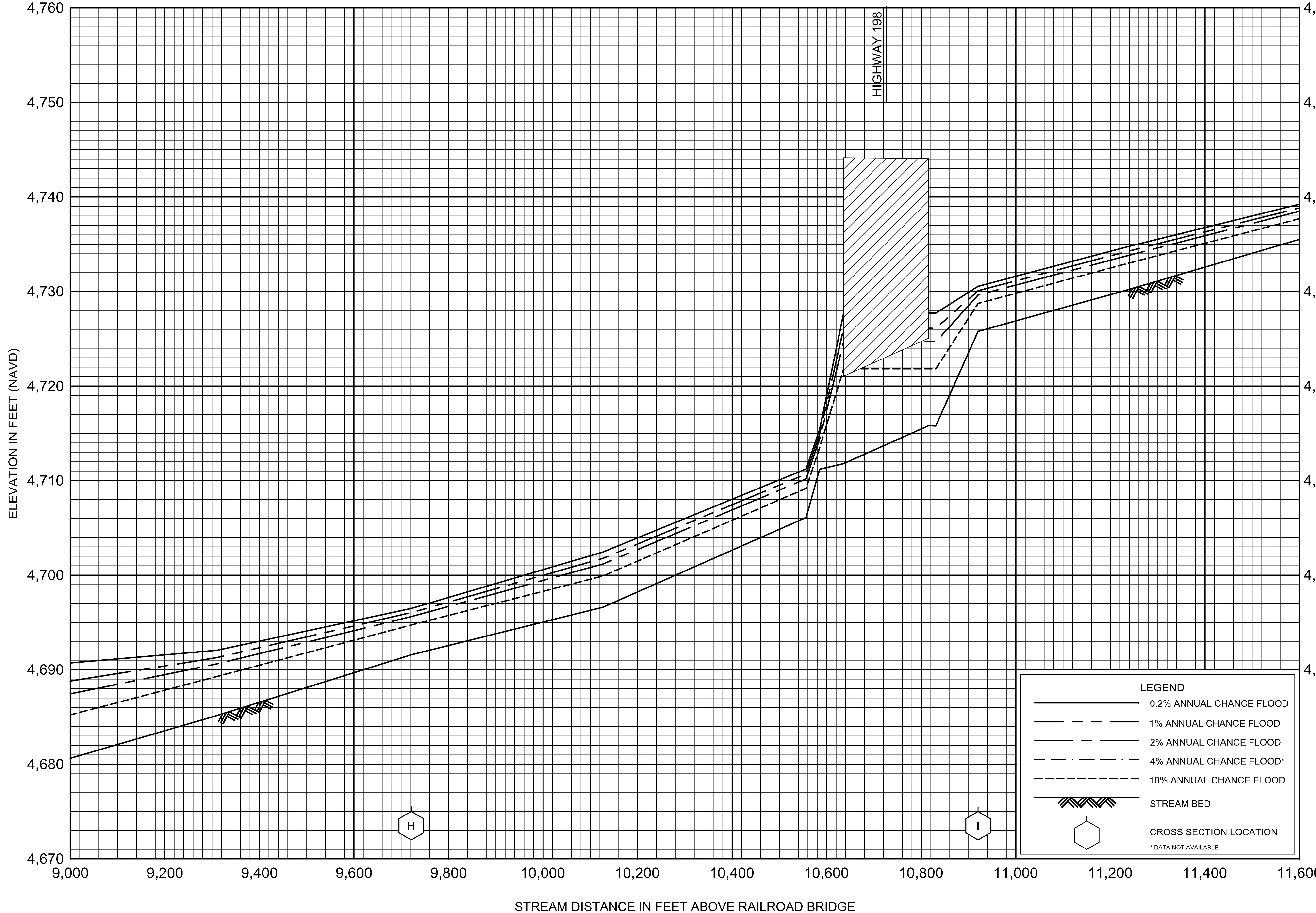
FLOOD PROFILES

DRY CREEK (PAYSON)

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS



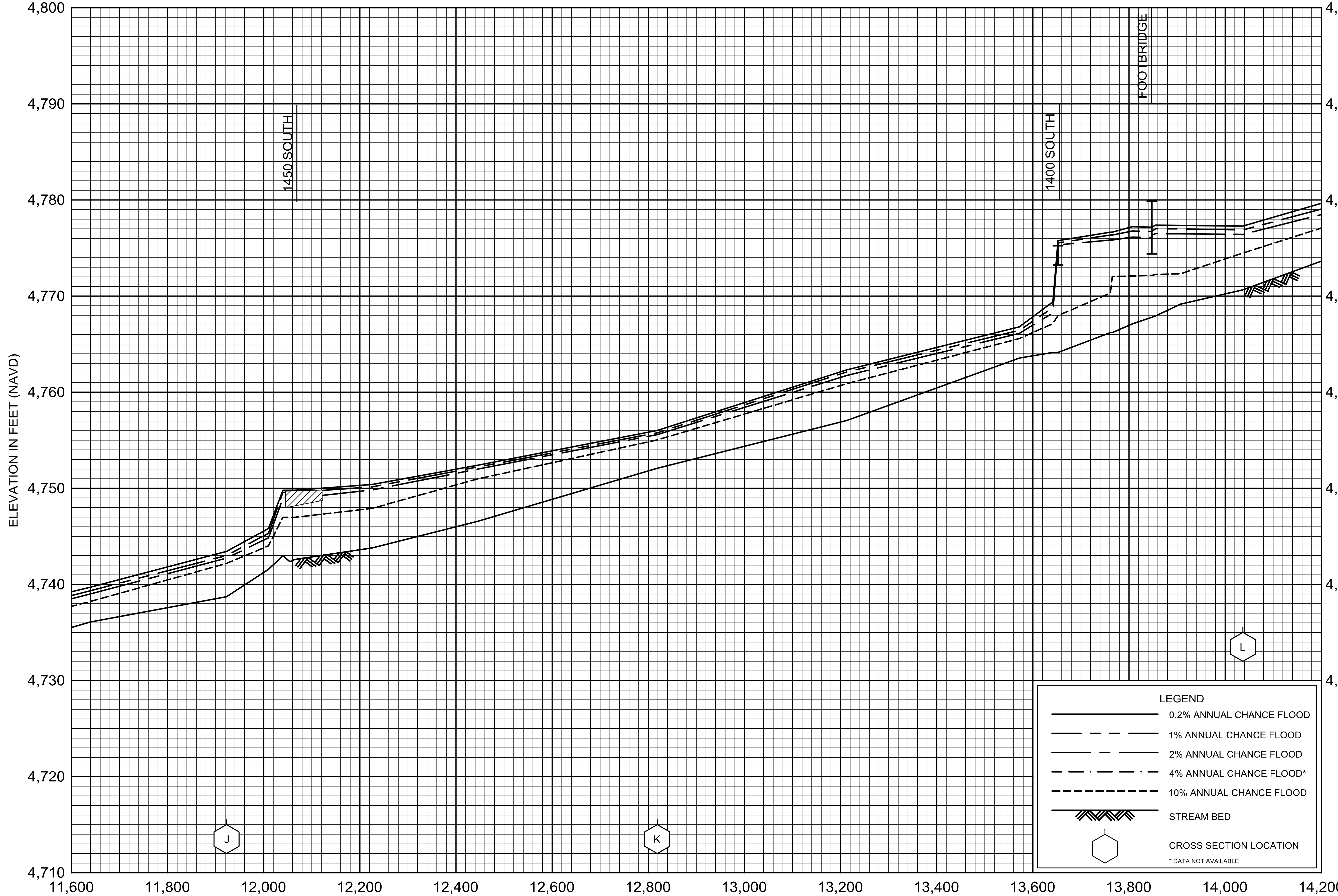
FLOOD PROFILES

DRY CREEK (PAYSON)

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS



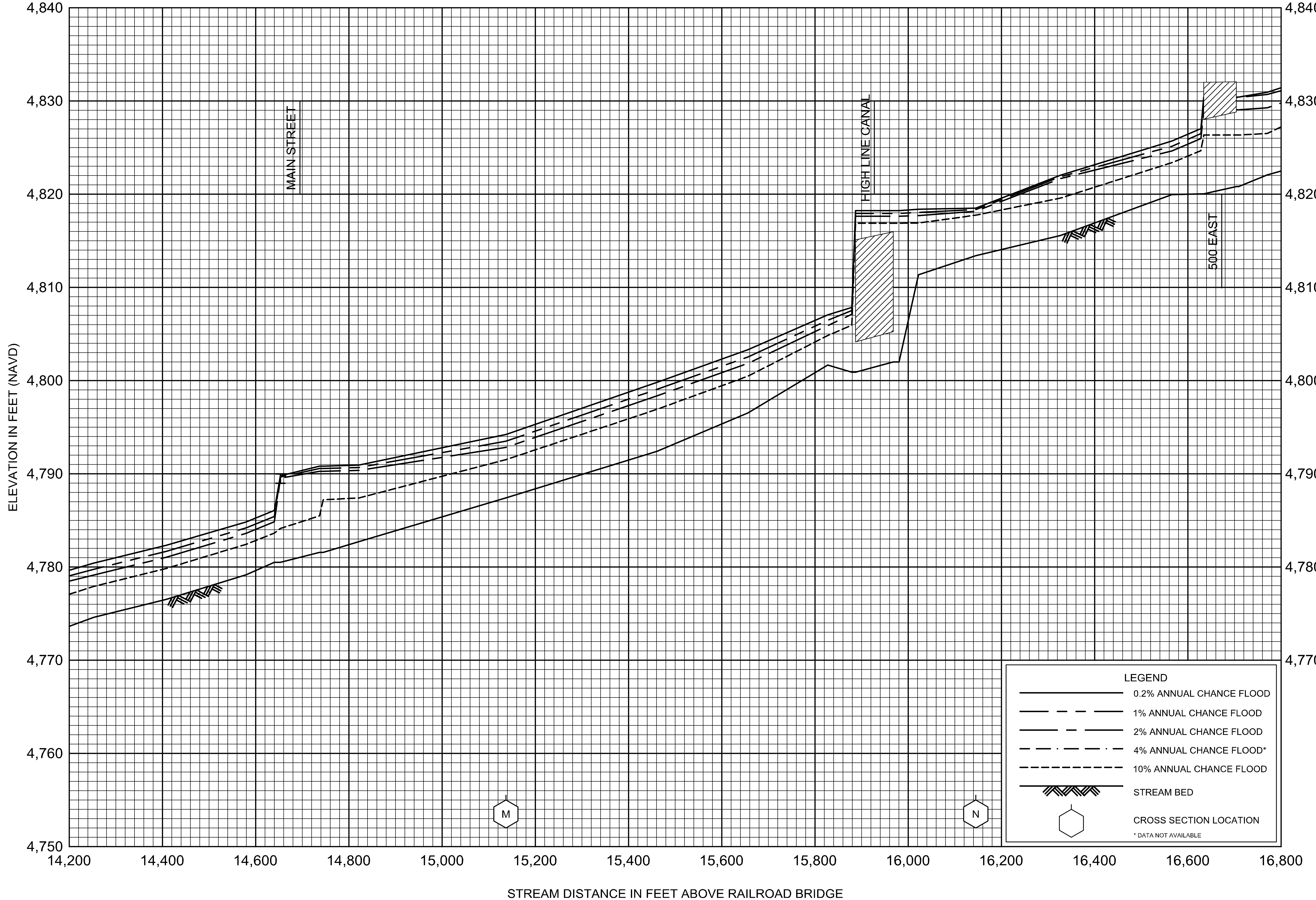
FLOOD PROFILES

DRY CREEK (PAYSON)

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS



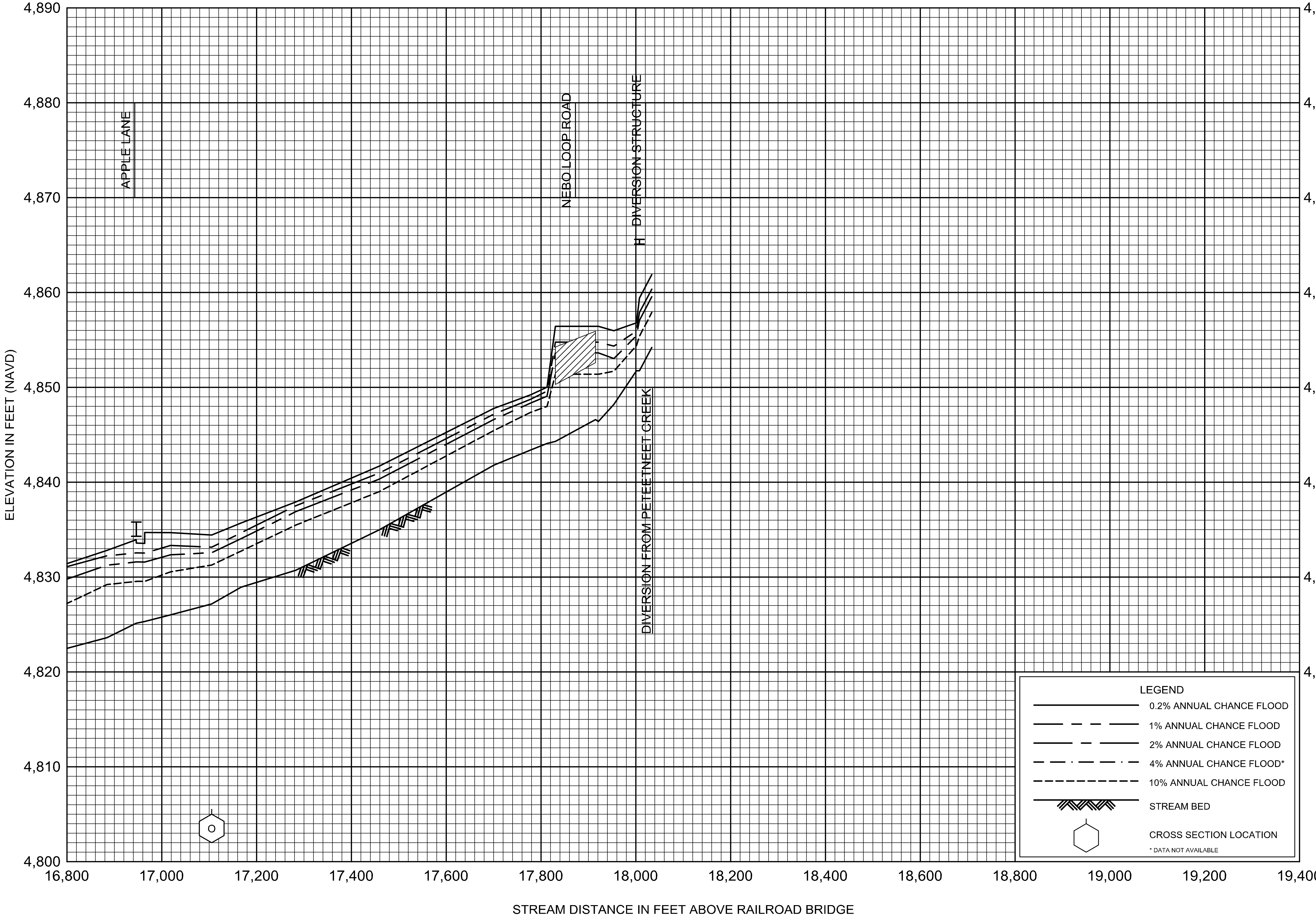
FLOOD PROFILES

DRY CREEK (PAYSON)

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS



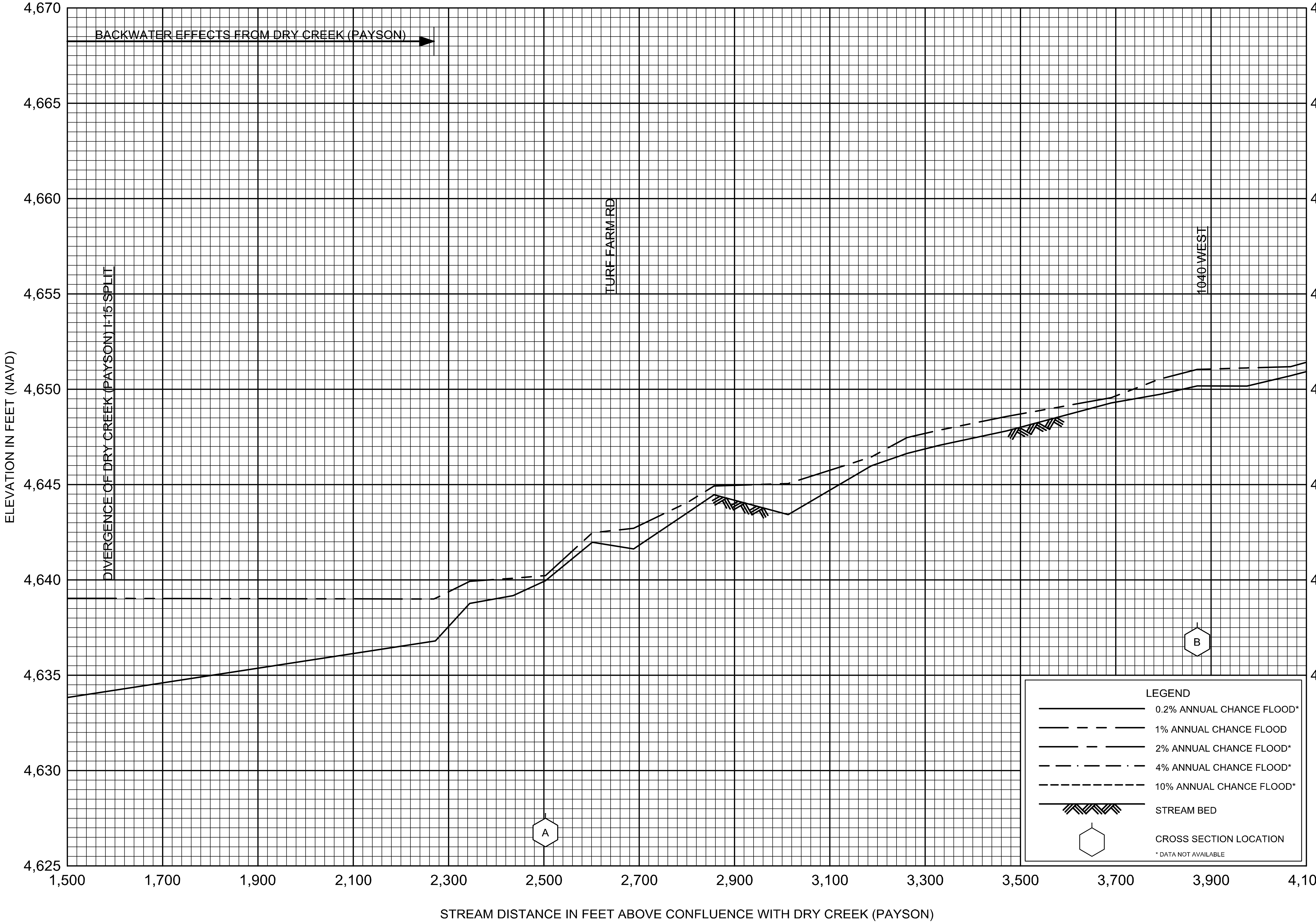
FLOOD PROFILES

DRY CREEK (PAYSON)

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS



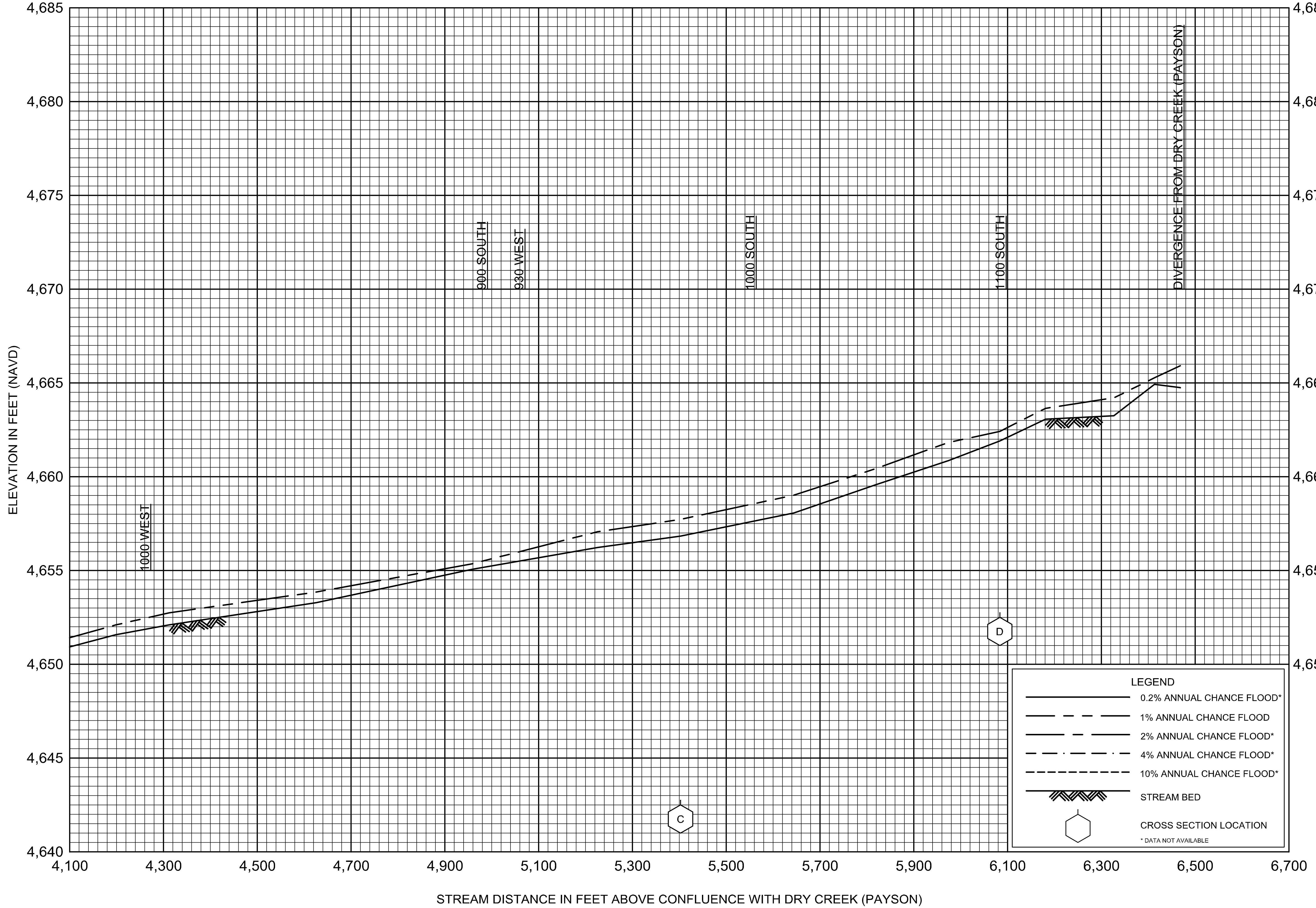
FLOOD PROFILES

DRY CREEK (PAYSON) 900 WEST SPLIT

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS



FLOOD PROFILES

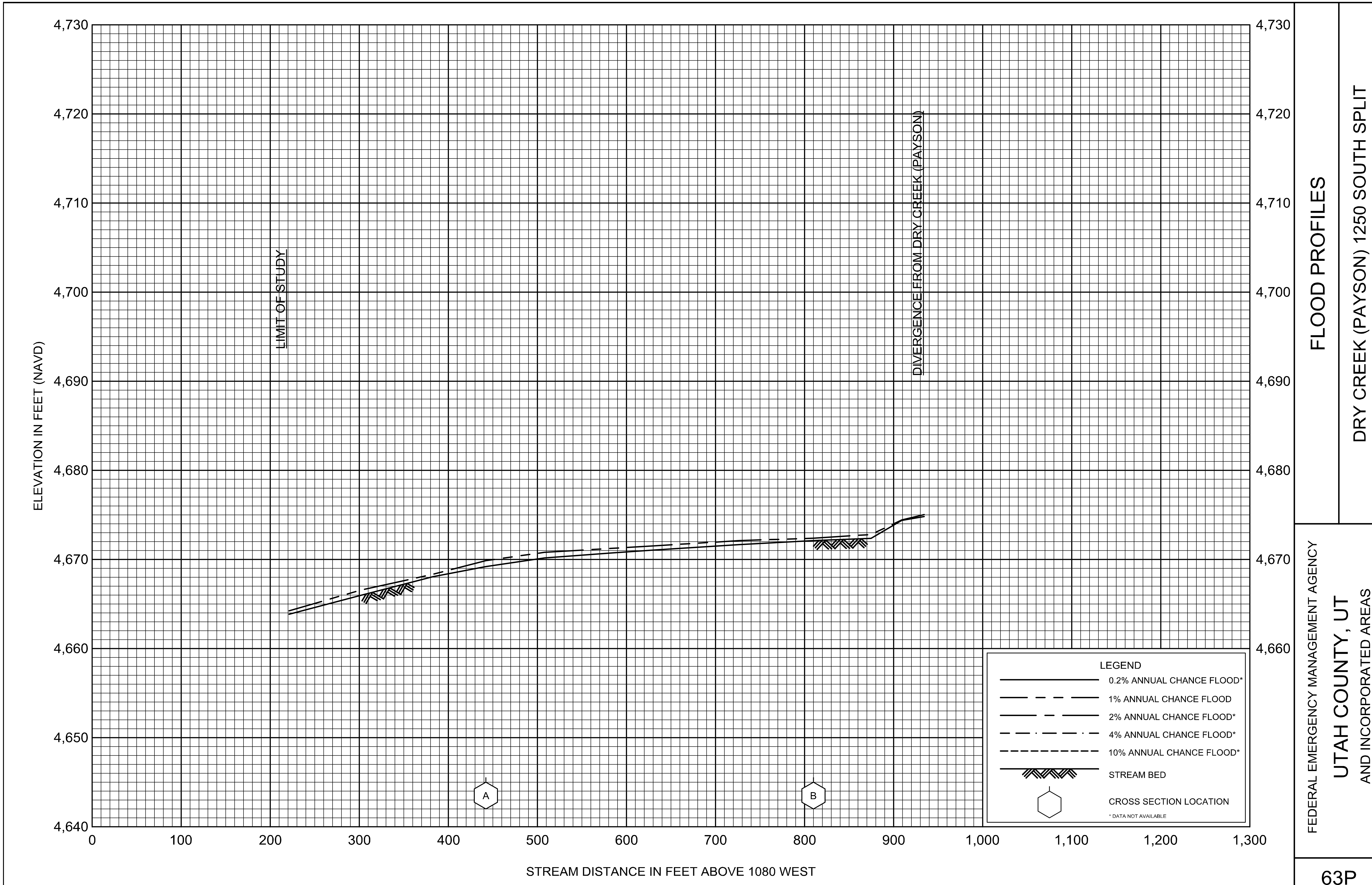
DRY CREEK (PAYSON) 900 WEST SPLIT

FEDERAL EMERGENCY MANAGEMENT AGENCY

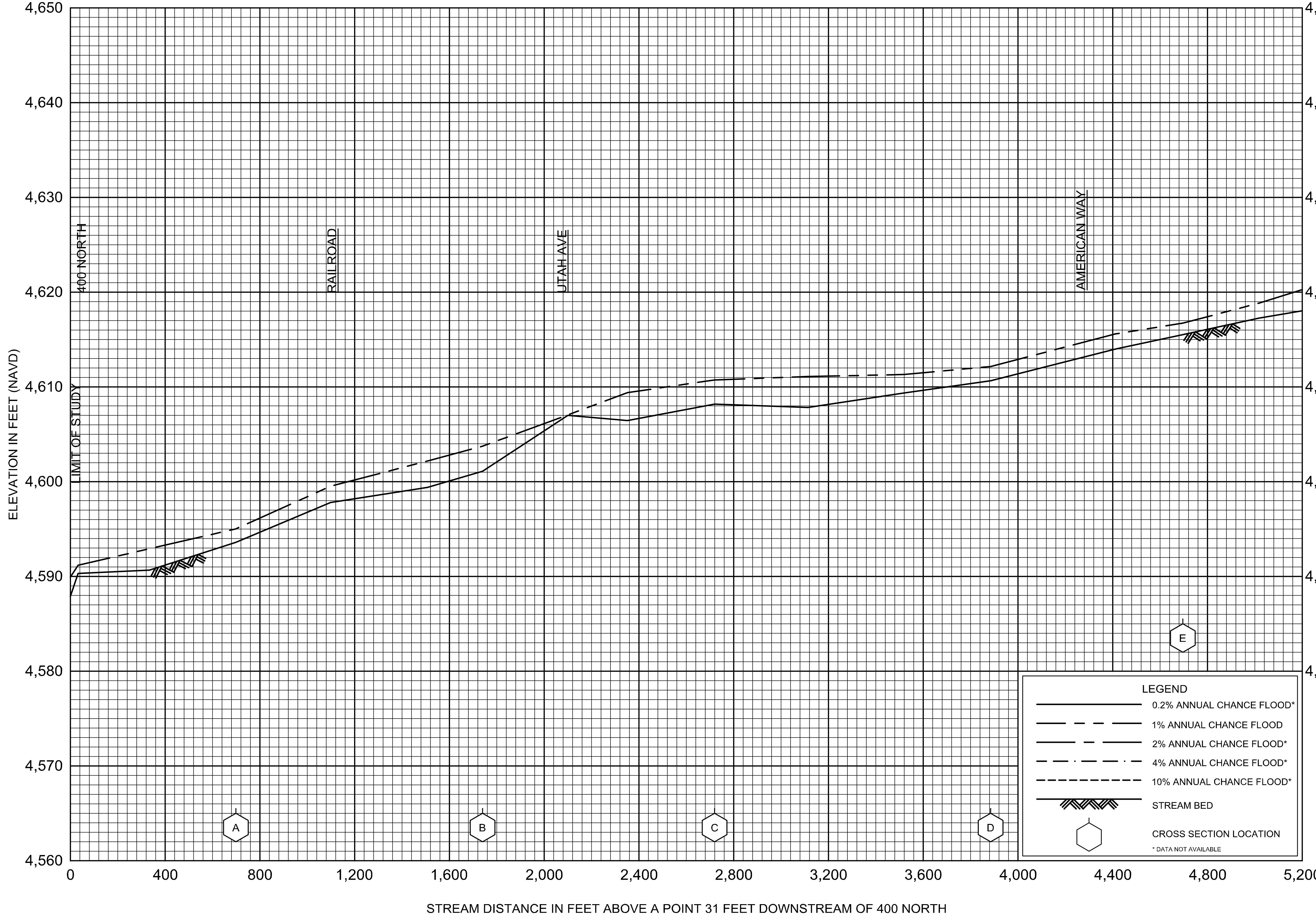
UTAH COUNTY, UT

AND INCORPORATED AREAS

62P



4,730
4,720
4,710
4,700
4,690
4,680
4,670
4,660
4,650
4,640
ELEVATION IN FEET (NAVD)
0
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300
STREAM DISTANCE IN FEET ABOVE 1080 WEST
LIMIT OF STUDY
DIVERGENCE FROM DRY CREEK (PAYSON)
A
B
LEGEND
0.2% ANNUAL CHANCE FLOOD*
1% ANNUAL CHANCE FLOOD
2% ANNUAL CHANCE FLOOD*
4% ANNUAL CHANCE FLOOD*
10% ANNUAL CHANCE FLOOD*
STREAM BED
CROSS SECTION LOCATION
* DATA NOT AVAILABLE
FLOOD PROFILES
DRY CREEK (PAYSON) 1250 SOUTH SPLIT
FEDERAL EMERGENCY MANAGEMENT AGENCY
UTAH COUNTY, UT
AND INCORPORATED AREAS
63P



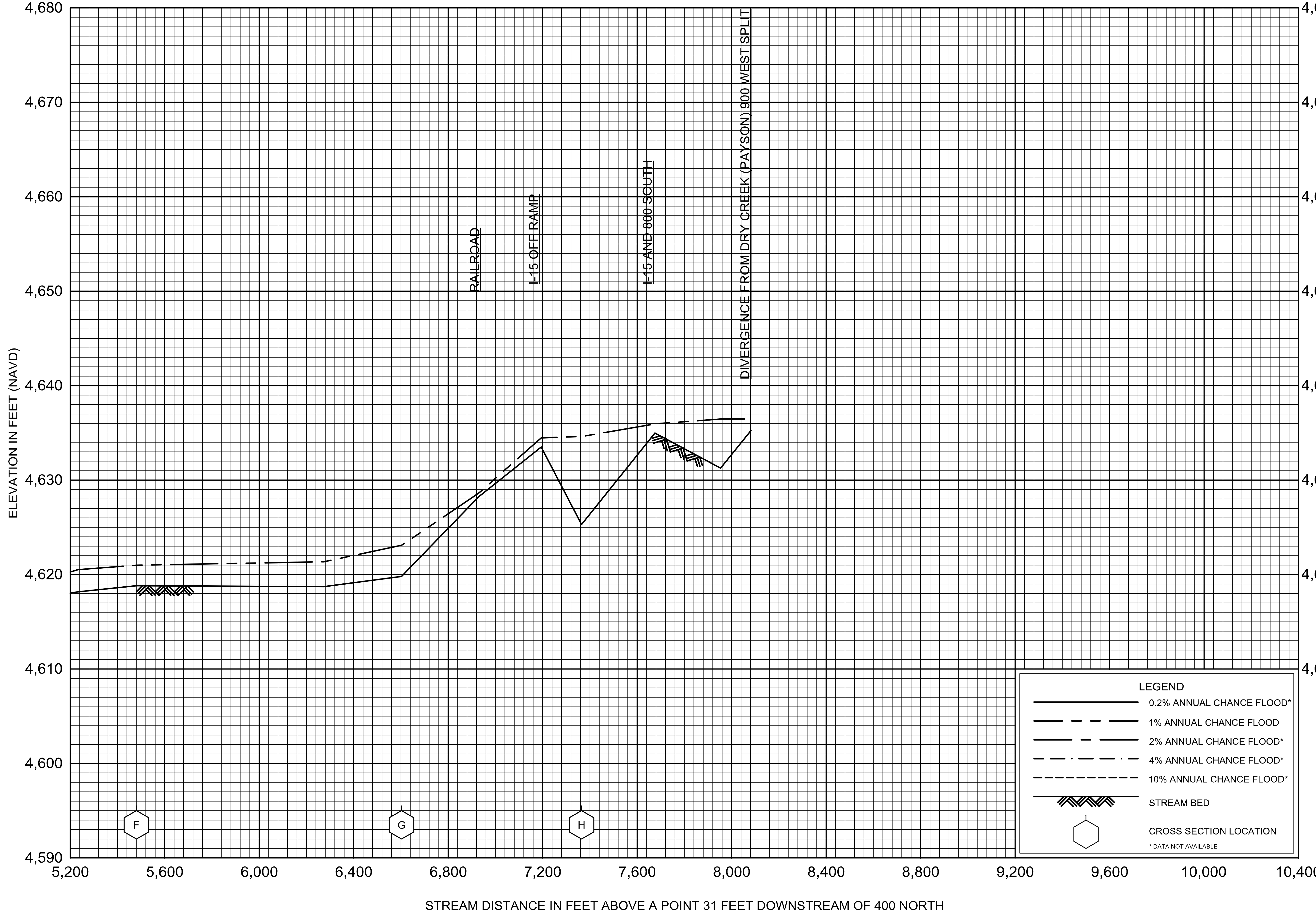
FLOOD PROFILES

DRY CREEK (PAYSON) I-15 SPLIT

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS



FLOOD PROFILES

DRY CREEK (PAYSON) I-15 SPLIT

FEDERAL EMERGENCY MANAGEMENT AGENCY

UTAH COUNTY, UT

AND INCORPORATED AREAS

APPENDIX F

LID GUIDE UTAH

UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
WATER QUALITY

A Guide to Low Impact Development within Utah

Prepared for:
Utah Department of Environmental Quality
Division of Water Quality

195 North 1950 West
Salt Lake City, UT 84116

DRAFT

September 2018

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epg Sustainable Solutions. Thriving Environments.

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Introduction

Purpose

This manual is to be used as a guide for incorporating low impact development (LID) approaches into development projects. It helps planners and designers in selecting what practices to incorporate in their site as well as municipal separate storm sewer systems (MS4s) in evaluating LID practices and determining what is most appropriate for their storm water programs. It is designed to comply with the goals of the Federal Clean Water Act (CWA) "to reduce the discharge of pollutants to the maximum extent practicable" (MEP).

This manual provides educational and technical information on LID best management practices (BMP), maintenance practices, vegetation selection, retaining the volume generated from the 90th percentile storm event, and other relevant information needed to assist decision makers, planners, designers, and reviewers in making the best possible decisions for their storm water programs and developments while complying with Utah's Division of Water Quality (DWQ) storm water permit requirements.

Users of this manual are encouraged to seek out innovative and effective methods in addition to those discussed to meet site-specific conditions to achieve the key principles of LID and meet permit requirements. A wide array of LID approaches is presented; however, as with any discipline for any development, site-specific decisions from qualified personnel will always be required. While LID BMPs presented are commonly used, permittees must consider local climate, soil conditions, vegetation, and other factors to determine what will work best within the permittee's jurisdiction.

Low Impact Development

Low impact development refers to systems, either structural or natural, that use or mimic natural processes to promote infiltration, evapotranspiration, or harvest/reuse of storm water as close to its source as possible to protect water quality and aquatic habitat. LID practices at the regional and site-specific level preserve, restore, and create green space using soils, vegetation, and rainwater harvest techniques. These systems and practices are referred to as best management practices (BMP).

Green infrastructure (GI) includes LID practices but is a broader practice that also includes ecological services and approaches such as "filtering air pollutants, reducing energy demands, mitigating urban heat islands, sequestering and storing carbon, enhancing aesthetics and property values, and preserving and creating natural habitat functions." (United States Environmental Protection Agency, 2012)

Key LID Principles

- Mimic natural processes
- Promote infiltration, evapotranspiration, harvest/reuse
- Manage storm water close to source
- Site design planning at project conception

Urban development inherently introduces increased impervious surfaces, vehicle use, human activity, and other activities that introduce pollutants and create adverse hydrologic conditions that are detrimental to the quality of the site's storm water runoff. In the past, the goal of traditional storm water management was to convey these flows offsite as quickly as possible and giving little to no consideration to preserving open spaces or creating pervious areas where rainfall could be managed onsite (Figure 1). Flood control measures were provided and runoff eventually discharged to a receiving surface water. Often, the quality of the receiving water would degrade over time, impacting aquatic life and dependent ecosystems, including human life within the ecosystem.

Figure 1: Impervious parking lot with no pervious areas or storm water quality features.

Incorporating LID practices reduces the impact of development on natural waterways and watersheds and provides practical as well as aesthetic benefits. Drainage infrastructure construction costs can be reduced, for example, by conveying runoff through vegetated swales instead of through pipes. Pavers or other pervious surfaces can reduce the size of an onsite basin by retaining runoff within a subsurface storage layer. Bioretention areas can provide retention and treatment to improve water quality before discharging into a pipe network. These types of designs also enhance the aesthetics of the development and are generally viewed favorably by the public.

LID practices are not limited to long-term post-construction controls. Site design practices such as preserving natural area, reducing impervious areas, and disconnecting impervious areas are examples of LID practices at the planning level that will result in improved water quality. City leaders, engineers, developers, and other stakeholders are encouraged to consider and introduce LID practices at the project planning level to maximize the effectiveness of their LID strategy and have as minimal of a negative impact on water quality as possible.

Extensive research and educational materials have been developed over the last several decades to assist in the understanding and implementation of LID practices. See the Environmental Protection Agency's (EPA) website on low impact development for an overview of LID concepts: https://www.epa.gov/nps/urban-runoff-low-impact-development.

Projects Covered by the Manual

The guidance provided in this manual is directed towards any project where the long-term management of storm water is being considered. New development and redevelopment projects within a permitted MS4 that disturb greater than or equal to one acre, including projects less than one acre that are part of a larger common plan of development or sale, have specific LID requirements that must be met as part of DWQ's storm water program; however, all sites are encouraged to consider LID practices. This includes projects for permitted non-traditional MS4s such as universities, medical centers, and prisons.

Starting in 2019, storm water programs for municipalities who are Municipal Separate Storm Sewer Systems (MS4s) permitted under the DWQ's storm water program will be required to develop an LID approach for new development and redevelopment projects. As part of this approach, permittees will be required to retain on-site the precipitation from the 90th percentile storm event. This requirement is for small MS4s that are covered by the General Permit for Discharges from Small Municipal Separate Storm Sewer Systems (UTR090000) and the Jordan Valley Municipalities permit (UTS000001).

Storm Water Integration

Storm Water at the Jurisdictional Level

Successful integration of LID features and green infrastructure requires that jurisdictions be fully equipped to provide technical and planning guidance to stakeholders. Storm water master plans and technical guidance documents will guide stakeholders in developing their planning approach and design process. Permittees should be aware of receiving waters within their jurisdiction that have been listed as having impairments on the state's 303(d) list and those that have been identified as requiring or have an approved Total Maximum Daily Load (TMDL). An interactive map identifying such waters can be found at the DWQ's website for the 2016 Integrated Report: https://deq.utah.gov/legacy/programs/water-quality/monitoring-reporting/assessment/2016-integrated-report.htm.

Coordination begins at the jurisdictional level of the permittee. Organizational structures vary widely but implementation of storm water quality requirements will typically fall within the duties of the public works, utilities, engineering, maintenance, or land development groups. As the jurisdiction moves forward with the development of ordinances, land development standards, storm water master plans, review processes, and other similar activities, it may become necessary to have staff dedicated to storm water.

A jurisdiction that is unfamiliar with permit requirements will inevitably fail at implementation. Education within the jurisdiction and dedication towards compliance is requisite for those who wish to develop functioning storm water programs. Competing interests, budgetary constraints, lack of inter-departmental communication, and lack of support within the jurisdiction jeopardize implementation at the program level, the planning level, and ultimately at the project level.

Ordinances

Ordinances should be adopted or modified that make development within the jurisdiction amenable to LID principles and green infrastructure, or that mandate them. Site design practices can be addressed in ordinances to:

- Promote and preserve open spaces
- Include building footprint, height limits, and setbacks that help meet density goals
- Include an LID analysis as part of the site plan review
- Parking code should allow for the use of pervious surfaces within parking lots
- Encourage clustering development to increase green space within developments
- Allow the permittee to access BMPs if BMP ownership has been transferred

Creating zoning and ordinances that promote LID will create the groundwork for LID implementation. A gap analysis of existing codes will determine if existing codes are preventing LID principles from being implemented.

A gap analysis is a systematic approach to reviewing ordinances to determine how LID practices can be written into city codes. The results of the gap analysis will identify the objective, a reference to specific codes or standards, and give a recommendation for how the code can be modified (Table 1).

Table 1: Parking lot runoff gap analysis results.

Objective	**Code**	**Summary of Impediment**
Determine if rain gardens, bioretention cells, and other bioretention devices are permitted within parking areas.	*ORD 04-13.b* Vegetation within parking lots shall be within raised areas and protected by curbs.	The existing code does not permit storm water flows within parking lots to sheet flow into bioretention or vegetated areas.

An example of one such gap analysis was developed for the Central Coast Low Impact Development Initiative. Its development was based on the permit requirement for Small MS4s within California that directs permittees to review local planning and permitting processes to discover gaps or impediments impacting effective implementation of post-construction requirement. Landscaping is directly identified as a priority in the permit. The gap analysis identifies five areas related to the conservation and creation of landscapes (AHBL, 2017):

1. Vegetation conservation
2. Open space management
3. Rooftop runoff
4. Open space/cluster development
5. Street and parking lot standards

Ordinances within Utah

A review of current ordinances within Utah reveals that some cities have created or modified codes to address low impact development. Ordinances range from general descriptions of implementation to entire sections dedicated to storm water ordinances and design criteria.

City	**Category**	**Ordinance**
Spanish Fork	Land Use	15.4.16.085.F. Grades *"…The minimum grade allowed for any City street is zero-point forty-five (0.45) percent. The City Engineer or his/her designee may allow a minimum grade of zero-point thirty-five (0.35) percent if the roadway has incorporated Low Impact Development (LID) systems. The maximum grade allowed for any private driveway is 12%."*
Spanish Fork	Utilities	13.16.040.E. *"All site designs shall implement LID principles as defined in this Chapter and in the BMP Manual. Runoff rates from one lot to another may not exceed pre-existing conditions as defined by the City, nor in such a manner that may unreasonably and unnecessarily cause more harm than formerly."*
Moab	Zoning	17.80.050.10. *"Parking lots shall incorporate methods for storm water management utilizing low impact development (LID) techniques including, but not limited to:* *a. End-of-island bioretention cell(s) with underdrain(s) and landscaping;*

		b. Bioretention cells or biofiltration swales located around the parking perimeter; *c. Breached curb drainage inlets (or curb cuts) in the end-of-island bioretention cells and bioretention strips to collect runoff; or* *d. Bioretention cells installed between lines of parking stalls to increase the total treatment surface area of these systems."*
Salt Lake City	Stormwater Quality	Various. Section dedicated to storm water provide definitions, references to developed manuals, general performance criteria for storm water management, and other guidance.
Logan	Public Services	13.14.200.A. *"All site designs shall control the peak flow rates of storm water discharge associated with design storms specified in this chapter or in the BMP manual and reduce the generation of postconstruction storm water runoff volumes and water quality to preconstruction levels. These practices should seek to utilize pervious areas for storm water treatment and to infiltrate storm water runoff from driveways, sidewalks, rooftops, parking lots, and landscaped areas to the maximum extent practical to provide treatment for both water quality and quantity. Other low impact development (LID) methods are also encouraged."*

Retrofitting Programs

A retrofit program is the structured evaluation of existing development to identify possible improvements to infrastructure with the goal of creating or improving storm water quality design. Simple tasks may be part of a retrofit program, but it may also be robust to the point of receiving dedicated funding for development and implementation. Permittees are required to develop a ranking of control measures to determine those best suited for retrofitting.

Figure 2: Potential curb cut location into a swale.

Retrofit programs include activities such as adding curb cuts that allow runoff of impervious surfaces to enter green areas. Figure 2 shows an existing development that has a slightly depressed, curbed, vegetated area that is surrounded by impervious surfaces. Depending on grading of the site, potential conflicts with the existing utilities, and the environmental sensitivity of receiving waters, a curb cut or multiple curb cuts at the upstream end of the swale to allow parking lot runoff the be conveyed through it would be considered a retrofit. Water quality parameters such as the contributing drainage area, imperviousness, water quality volume, water quality flow, and the swale's geometry should be analyzed to determine the impact of the retrofit. Additional analysis would be needed to determine the potential contributing drainage area if a curb cut were to be made at the upstream end. Figure 3 reveals that a curb cut was made at the corner of the parking lot, suggesting that standing water was present. Regrading of the parking lot might be necessary for this site to redirect all possible flows to the upstream end of the swale.

Retrofit programs are unique to the jurisdiction; however, prioritizing retrofitting opportunities based on geography and environmental need will assist in determining where efforts should be focused. The following factors must be considered (Stormwater Retrofit Techniques for Restoring Urban Drainages in Massachusetts and New Hampshire: Small MS4 Permit Technical Support Document, 2011):

- Proximity to waterbody
- Status of waterbody to improve impaired waterbodies and protect unimpaired waterbodies
- Hydrologic condition of the receiving waterbody
- Proximity to sensitive ecosystem or protected area
- Any upcoming sites that could be further enhanced by retrofitting storm water controls

Figure 3: Curb cut at downstream end of parking lot.

The general steps below can be used in the development of a retrofit program:

1. Identify local need and capacity for storm water retrofitting. Determine if any watersheds in MS4 are 303d listed or have TMDLs.
2. Identify potential locations connected to the MS4 including publicly owned properties, right-of-way, culverts, and existing detention practices that lack adequate storm water practices.
3. Visit potential locations to verify current conditions and identify potential retrofit BMP options.
4. Create inventory of potential locations with site sketches, photos, and basic hydraulic calculations.
5. Based on the permittee's developed ranking of control measures, evaluate retrofit options for factors like performance, cost, community support, and feasibility.
6. Model treatment benefits for chosen retrofitting option to determine most cost-effective approach.
7. Once most cost-effective option is determined, move project to design and construction phase. Allow time for sites surveys, permitting, bidding, and specifications.

The LID BMPs in this manual can be used to retrofit existing sites. Other possible retrofitting control measures are described below.

Figure 4: Multi-stage overflow outlet with trash screen.

Curb Cuts

Identify areas where introducing a curb cut will result in flows being diverted from gutters into vegetated areas. A curb cut detailing a depression within the curb may be needed to ensure that flows don't bypass the curb cut. Regrading of the vegetated receiving area and inlet protection may be necessary on the downstream side of the cut.

Dual-Purpose Basins

Retrofitting the outlet structure of a flood control basin creates a dual-purpose basin that accommodates flood control flows and storm water flows (Figure 4).

Determine the water quality volume of the contributing drainage area and provide an outlet near the bottom of the structure that releases the water quality volume within an acceptable drawdown time. Modification of the outlet structure can be as simple as adding orifices to a pipe riser or could require design of a new outlet structure.

Perform infiltration testing (or obtain from project plans) within the basin to determine the infiltration rate of the soils within the basin. If infiltration rates are appropriate for retention, the detention basin will also function as an infiltration basin.

Trash Capture Devices

Trash collection devices are installed as in-line systems or end-of-pipe systems to prevent gross solids from entering a receiving water or basin. In-line systems require more design effort and expense for retrofitting but end-of-pipe systems such as that seen in Figure 5 are easier to install retroactively to a pipe end section depending on the end section configuration.

Linear radial devices are another type of end-of-pipe trash collection device that can be installed at the end of an inflow pipe in the basin bottom.

Figure 5: End-of-pipe trash netting.

Alternative Compliance and Credit Systems

Alternative Compliance

Alternative compliance refers to measures that provide water quality benefits either on-site or off-site when it is technically infeasible to retain the 90th percentile volume. This is done within the project limits, within the watershed or subwatershed of the project, or on a regional level. If retention of the 90th percentile volume is technically infeasible for a project, possible alternative compliance measures include:

- Implementation of BMPs that provide water quality treatment such as bioswales, filter strips, etc.
- The creation of off-site retentions area within the original project's subwatershed that is sized for the volume unable to be captured.
- Establishment of a credit system that allows for the tracking of volume reduction and pollutant reduction throughout the permittee's jurisdiction.

Credit Systems

In its simplest form, a credit system is a database of projects that documents project volume retention goals and the actual volume retained. This applies to pollutant reduction goals as well. Regional BMPs can be used within the credit system. Permittees can retain additional runoff at one project location to account for runoff that may have been technically infeasible to retain at other project locations.

A few examples of credit systems and other alternative compliance programs are briefly explained below. Links to additional credit systems in use throughout the country is found below the examples (Table 2).

Minnesota Pollution Control Agency

The state of Minnesota credit system quantifies storm water runoff volume and pollutant reduction. Every cubic foot of the design storm (1") that is captured is counted as a credit. Pollutant removal is counted as 1 credit based on the unit of measurement for the pollutant. For example, if a BMP removes 10 pounds of phosphorus per year, it is counted as 10 credits. Multiple credits can be claimed for each BMP depending on its function. A bioretention area that removes multiple pollutants cam claim credit for the volume reduction and the reduction of any pollutants.

Credits can be used towards the following:

- To meet a TMDL waste load allocation.
- To meet the Minimal Impact Design Standards performance goal.
- To provide incentive to site developers to encourage the preservation of natural areas.
- To reduce costs associated with BMPs.
- To supplement the Minnesota Pollution Control Agency Construction General Permit or be used for projects not covered under the CGP.
- As part of the financial evaluation under a local storm water utility program. (Kieser & Associates, LLC, 2009)

San Diego County

San Diego County does not have a credit program but instead implements an Alternative Compliance program. Alternative Compliance programs are implemented in areas that are unable to retain 100% of the water quality volume (WQV) on-site. There may be several reasons as to why the WQV cannot be handled on-site including poorly infiltrating soils, high groundwater, and concerns with pollutant mobilization. San Diego County has identified the following measures for alternative compliance:

- Stream or riparian area rehabilitation
- Retrofitting existing infrastructure for storm water retention or treatment
- Groundwater recharge projects
- Regional BMPs
- Water supply augmentation projects
- Floodplain preservation through land purchase. (California Regional Water Quality Control Board San Diego Region, 2015)

Los Angeles County

Like San Diego County, Los Angeles County does not have a credit program but instead implements an Alternative Compliance program. Los Angeles County has identified the following measures for alternative compliance:

- On-site biofiltration
- Offsite infiltration
- Groundwater replenishment projects
- Offsite retrofitting projects
- Regional storm water mitigation programs.

If using biofiltration, the county requires the project to biofiltrate 1.5 times of the WQV that cannot be retained on-site. Offsite infiltration requires a project to retain the portion of the WQV that is unable to be retained on-site as well as reduce pollutant loads from the runoff. Groundwater replenishment projects are required to intercept the WQV not retained on-site through infiltration, bioretention, or groundwater replenishment BMPs. These projects are required to be located in the same sub-watershed as the development. For retrofitting projects, developers are required to retain the WQV not retained on-site through BMP measures at a site with similar land uses as the development. The regional storm water mitigation program option allows permittees to create a program for handling runoff on a regional or sub-regional scale. The program must meet certain criteria and be approved by the Regional Water Board Executive Officer. (California Regional Water Quality Control Board Los Angeles Region, 2016)

Table 2: Nationwide storm water programs using credit systems.

State or Local Storm Water Guidance Document	Web Link
Vermont Storm Water Management Manual	http://dec.vermont.gov/
Minnesota Storm Water Manual	https://www.pca.state.mn.us/water/minnesotas-stormwater-manual
Philadelphia Storm Water Management Guidance Manual	https://www.phillyriverinfo.org/
New Jersey Storm Water Best Management Practices Manual	https://www.njstormwater.org/bmp_manual2.htm
Maryland Storm Water Design Manual	https://mde.maryland.gov/programs/Water/StormwaterManagementProgram/Pages/index.aspx
Georgia Storm Water Management Manual	https://atlantaregional.org/natural-resources/water/georgia-stormwater-management-manual/
Pennsylvania Storm Water Best Management Practices Manual	https://www.dep.pa.gov/Pages/default.aspx
Ontario Storm Water Management Planning and Design Manual	https://www.ontario.ca/page/ministry-environment-conservation-parks
Storm Water Management Manual for Western Washington	https://ecology.wa.gov/Regulations-Permits/Guidance-technical-assistance/stormwater-permittee-guidance-resources/stormwater-manuals

Source: Center for Watershed Protection

Storm Water at the Project Level

Incorporating LID principles at the planning stages of a development will increase the likelihood that they will be able to be integrated into the site (Figure 6). If LID is considered late in the design, it becomes more expensive to implement due to costs associated with redesign of the site layout, additional geotechnical studies, or coordination with environmental, watershed management groups, or other state or federal agencies. Integration of LID principles should be done by qualified engineers who understand the goals of the project, the requirements within the permittee's jurisdiction, and the design criteria for the BMPs.

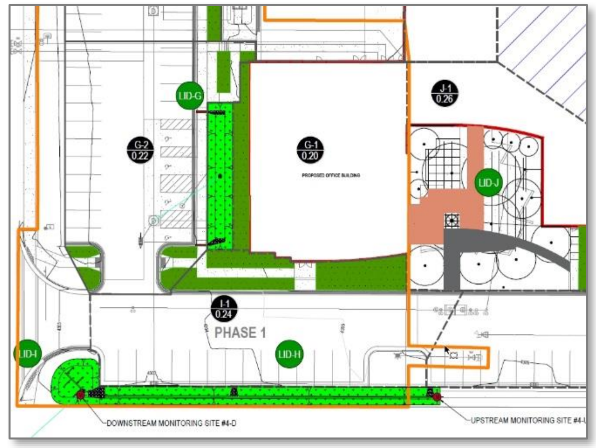


Figure 6: LID BMPs shown in site plans.

Collaboration amongst a project's stakeholders for inclusion of LID principles should occur as part of the regular project development, as would be the case for other design elements like grading, utilities, and flood control. As the design progresses, project meetings should include discussion on the storm water elements of the project to ensure that water quality requirements are being met to the maximum extent practicable and that the LID approach is functional and compatible with the site's hydraulic design. Additional meetings and coordination to address design details and/or conflicts should be expected. A list of potential project team members who will be involved in the coordination and/or design of LID features is presented in Table 3.

Table 3: Low impact development project team.

Jurisdiction/Permittee		**Site Designer/Developer/Architect**
MUNICIPALITY	NON-TRADITIONAL MS4s	Project Manager
City Engineer	Facilities Director	Civil Engineers
Public Works	Project Coordinator	Geotechnical Engineers
Utilities	Utilities	Lead Architect
Planner	Planner	Landscape Architects
Maintenance	Maintenance	Landscape Engineers
Landscaping	Landscaping	Environmental Engineers

Site Consideration

Gather subsurface, geotechnical, topographical, and any other technical information about the site to incorporate into the site design. Site conditions will dictate an appropriate LID approach by revealing opportunities or identifying limitations.

Soils

Soil conditions will determine if certain LID approaches are feasible. Soils that are classified as Hydrologic Soil Group 'A' are generally acceptable soils for bioretention and infiltration BMPs. 'B' soils may not be acceptable for infiltration and bioretention. 'C' and 'D' soils generally are not. The Hydrologic Soil Group is a planning level analysis of soils. For design, geotechnical reports should determine if the existing soils are acceptable.

Groundwater

Infiltration should not occur within areas of shallow groundwater as it may lead to flooding of the BMP or introduction of pollutants into the groundwater. Measurements should be taken at each BMP location to determine the depth to groundwater. The following groundwater resources are available for planning level decision making:

Hydrogeology of Recharge Areas and Water Quality of the Principal Aquifers along the Wasatch Front and Adjacent Areas, Utah – A snapshot of the overall hydrogeology within the Wasatch Front area of Utah. https://pubs.usgs.gov/wri/1993/4221/report.pdf

Groundwater Conditions in Utah, Spring of 2017 – An annual report on groundwater conditions within Utah. https://ut.water.usgs.gov/publications/GW2017.pdf

Utah Active Water Level Network, USGS – Active monitoring of groundwater wells throughout the state. https://groundwaterwatch.usgs.gov/StateMap.asp?sa=UT&sc=49

Existing drainage patterns

Drainage patterns will be readily evident for any redevelopment project either from visual observation or from plan sets. Determine the constraints introduced by the existing storm drain network such as pipe capacity and inlet and outlet elevations. For new development projects, determine the existing drainage patterns as determined by the site's topography. It is more likely that the site's pre-development hydrology can be mirrored if the design maintains the original drainage patterns and paths.

Existing pervious areas and vegetation

If existing pervious areas can support bioretention or already provide bioretention, maintain them or otherwise make them a part of the site design. Taking advantage of natural depressions or areas of vegetation is an ideal and cost-effective alternative to grading and design. Keep trees and other vegetation on site when possible.

Site Design Practices

Storm water treatment and retention is most effective when done close to its source. Site design practices accomplish this by taking advantage of approaches that aren't necessarily quantifiable but that are aimed at reducing the overall impact of the development.

Figure 7: Bioretention within parking lot.

Reduction of Impervious Surfaces

Reducing impervious surfaces, preserving pervious surfaces, or creating pervious surfaces (Figure 7) provides multiple benefits to storm water quality. From a storm water quality standpoint, the potential for treatment is higher for runoff that lands on the pervious surface instead of on an impervious surface. Pervious surfaces with 'good' soils will infiltrate more runoff from the more frequent storms. From a design standpoint, increasing the pervious area decreases the total runoff from the site. Pervious surfaces also provide the opportunity to add shade trees or other types of vegetation that will increase the aesthetic appeal of the site.

Disconnected Impervious Areas

The practice of directly connecting impervious areas is ubiquitous as traditional designs encouraged the removal of runoff as quickly as possible. This practice leads to the inherent hydrologic results of increased volume from rain events and increased peak flows. Treatment of runoff is virtually nonexistent as it is conveyed from rooftop to sidewalk to parking lot to catch basin to receiving water, taking with it all the pollutants it encounters in its path. Disconnecting impervious areas by introducing pervious areas or rerouting flows from impervious surfaces (Figure 8) slows down flows and reduces the volume discharged to the downstream storm drain network or removes it entirely. Treatment is also provided through bioretention and biofiltration.

Figure 8: Disconnected impervious areas.

Curb Cuts

Curb cuts can be part of a site plan or be introduced retroactively as part of a retrofit program. Curb cuts are a simple way to convey flows from an impervious surface to a pervious surface (Figure 9). Roadways and parking lots are prime locations to investigate whether curb cuts can be used to divert flows from a traditional storm drain network to a pervious area or a bioswale, bioretention or infiltration area, or another type of BMP.

Figure 9: Curb cuts to a rock lined swale.

Additional site design practices (Minnesota Pollution Control Agency, 2017)

- Preserving natural areas
- Natural area conservation
- Site reforestation
- Stream and shoreline buffers
- Open space design
- Disconnecting and distributing runoff
- Soil compost amendments
- Disconnection of surface impervious cover
- Rooftop disconnection
- Grass channels

- Storm water landscaping
- Narrower streets
- Reducing impervious cover in site design
- Narrower streets
- Slimmer sidewalks
- Smaller cul-de-sacs
- Shorter driveways
- Smaller parking lots

Documentation

Permittees may wish to require documentation that a project's LID approach and design are consistent with the permittee's requirements. A template for documentation is provided in Appendix A. The storm water quality report template provides permittees a sample of project documentation that ensures consistent design within the permittee's jurisdiction and verifies compliance with LID considerations and retention requirements. The report may be used during a project's design and review process and be required as part of a project's submittal documents to ensure that water quality requirements have been met to the maximum extent practicable. The template can be altered as needed by the permittee. Sample text is highlighted.

The 90th Percentile Volume

LID Impact on Hydrology

Over the last several decades as municipal and DOT storm water programs around the country have increased their efforts to comply with the Clean Water Act of 1972 and their associated MS4 permits, storm water programs have tended to focus on the goal of mimicking predevelopment hydrologic conditions. LID BMPs, green infrastructure practices, and retention of the 90th percentile volume are tools and requirements that are used to accomplish this goal.

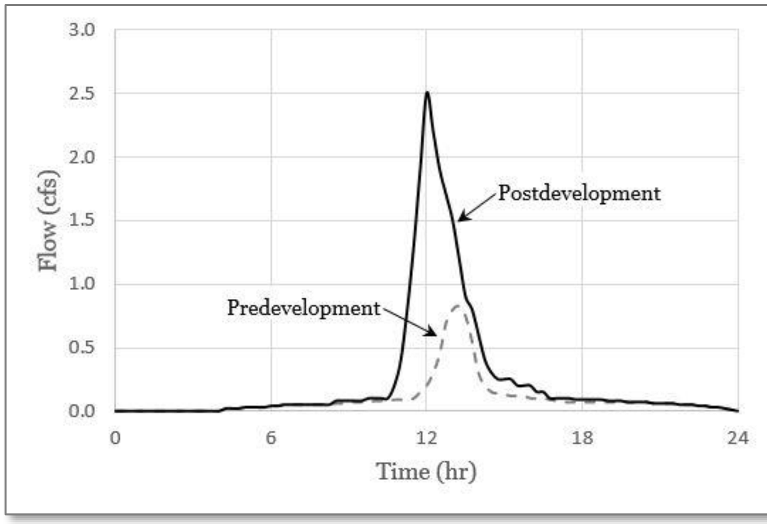


Figure 10: Typical hydrologic impact of development on site hydrology.

Urbanization inherently increases the imperviousness of an undeveloped site. This increase in impervious area impacts the site's hydrology. More frequent peak flows, higher peak flows, and higher runoff volumes are well-documented hydrologic impacts (D.B. Booth, 1997; Konrad & Booth, 2002) (Figure 10).

Traditional approaches to storm water management removed runoff from the site by quickly conveying flows to a storm drain network. This approach protects life and property and need not be jeopardized by low impact design principles.

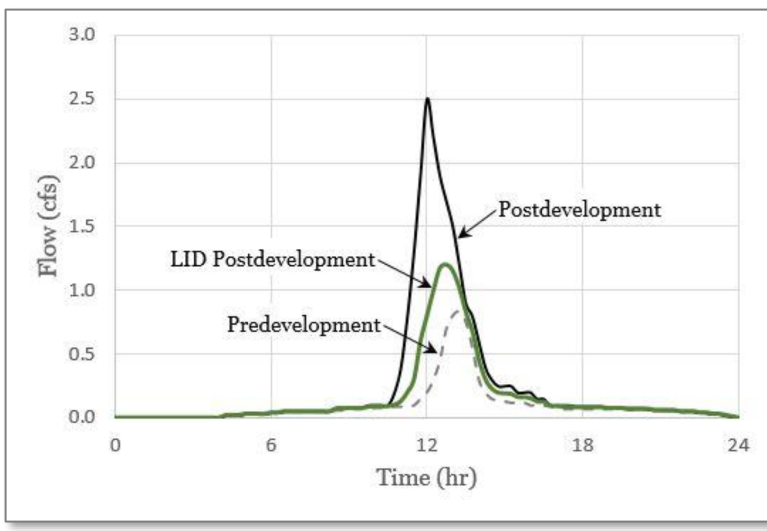


Figure 11: General post development hydrograph with LID.

An LID approach to site development produces a hydrologic condition that more closely mimics the pre-development hydrologic condition. Peak flows are reduced and are less frequent (Figure 11); runoff volume is also reduced (WEF Press, 2012).

Developing the 90th Percentile Volume

Project Volume Retention Goal, V_{goal} – The volume of runoff generated within the project limits over a 24-hour period during the 90th percentile storm event.

Water Quality Volume, WQV – The volume of runoff generated within a BMP's drainage area over a 24-hour period during the 90th percentile storm event.

The following steps may be used to determine the project volume retention goal and the water quality volume.

Step 1: 90th Percentile Depth

Determine the 90th percentile precipitation depth.

1. Obtain long-term daily rainfall data
2. Sort data low to high.
3. Edit out snowfall and small events (<0.1 inch).
4. Use the Excel PERCENTILE function to calculate the 90th percentile rainfall depth.

A more in-depth discussion on determining the 90th percentile precipitation depth is found here: https://deq.utah.gov/legacy/topics/fact-sheet/docs/handouts/2016/05may/calculation-90-percentile-storm-event.pdf.

Step 2: Runoff Coefficient

Determine the runoff coefficient.

The runoff coefficient represents the effects of runoff interaction with the surface over which it flows. Runoff coefficients for small, frequent storms such as for the 90th percentile are not equivalent to runoff coefficients for large, less-frequent storms such as the 10-yr event and greater that are used with the Rational Method. The effects of infiltration, retention, and interception are increased for the smaller storm events compared to the larger events. Because of this, runoff coefficients for smaller storms are numerically smaller than for larger storms.

Various coefficients for smaller storms have been developed through research. A brief summary of three runoff coefficients is given below. Permittees are encouraged to research these and other runoff coefficients or develop their own in determining which method to use within their jurisdiction for use with the 90th percentile storm. Deciding on a single runoff coefficient methodology will simplify the design and review process. For all of these equations, *i* represents the imperviousness of the drainage area.

A more in-depth summary of several runoff coefficients and a survey of runoff coefficients used throughout the country by municipalities and departments of transportation was developed by the California Department of Transportation (CALTRANS) and published as a Technical White Paper titled *Runoff Coefficient Evaluation for Volumetric BMP Sizing*.

Method 1

A regression model based on the imperviousness of a tributary area in determining the average annual rainfall for the project site. This equation was derived by removing outliers from previous datasets used for research into runoff coefficients and therefore reduces the impact of erroneous measurements. (California Department of Transportation Division of Environmental Sciences, 2015) It is referred to in this manual as the Reese method.

$R_V = 0.91i - 0.0204$

Method 2

Based on the imperviousness of approximately 50 sites, a simple linear regression was created to estimate the runoff coefficient. (California Department of Transportation Division of Environmental Sciences, 2015)

$R_V = 0.9i + 0.05$

Method 3

Regression equations for runoff coefficient equations based on NRCS soil groups for the 2-year event. (Guo, 2013)

Table 4: Runoff coefficient equations based on the NRCS Soil Group.

NRCS Soil Group		
A	**B**	**C/D**
$R_{V\text{-}A} = 0.84i^{1.302}$	$R_{V\text{-}B} = 0.84i^{1.169}$	$R_{V\text{-}C/D} = 0.83i^{1.122}$

Step 3: Imperviousness

To determine the project's volume retention goal, determine the imperviousness of the project limits. To determine the water quality volume of a BMP's drainage area, determine the imperviousness of the drainage area. The imperviousness of the BMP drainage area will include any off-site impervious areas that are part of the BMP's drainage area.

Project imperviousness = Impervious area / Project limits

BMP imperviousness = Impervious area within BMP drainage area / BMP drainage area

Step 4: 90th Percentile Volume

Calculate the 90th percentile volume using the following equations for V_{goal} or WQV.

$$V_{goal} = R_V dA \quad \text{or} \quad WQV = R_V dA$$

Where:

V_{goal} and WQV = 90th percentile volume, cf

R_V = Runoff coefficient

d = 90th percentile precipitation depth, ft

A = Project area or BMP drainage area, sf

Local Case Studies

Preface to Case Studies

The following case studies are examples of low impact development features that were designed with the purpose of collecting urban storm water. They are significant because they demonstrate that within Utah's semiarid climate, bioretention and low impact development approaches can be successfully implemented. Three of the sites are within Salt Lake County and one is in Grand County.

The sites discussed are:

- Bioretention Area at The University of Utah

  A bioretention area at the campus captures parking lot runoff.

- Bioretention Area at Mountview Park in Cottonwood Heights

  A bioretention area within a large park captures runoff from parking lots within the park and from a nearby residential area.

- Various LID BMPs at the Sandy City Public Works facility

  Rain gardens, bioswales, vegetated swales, concrete pavers, and permeable asphalt detain and treat runoff from a public works facility.

- Permaculture Garden at Utah State University Moab

  As part of a landscaping renovation at the campus, impervious areas are converted to infiltrating swales and increased pervious surfaces that sustains various plant life.

As part of the evaluation of these sites, calculations were performed to determine whether the sites would be able to successfully retain the 90^{th} percentile storm depth for BMPs' drainage areas. The bioretention areas at The University of Utah and Mountview are undersized for the 90^{th} percentile storm depth. The BMPs at the Sandy City Public Works were designed with the 90^{th} percentile storm volume in mind and four of the nine BMPs were able to be sized for the full water quality volume. Approximate calculations for the 90^{th} percentile storm volume for the Utah State University Moab site were made.

Location*: 40.7643°, -111.8422

Contributing Drainage Area: 1.56 ac

Imperviousness: 100%

Bioretention Footprint: 1100 sf

Infiltration Rate (in-situ): up to 7.9 in/hr

Soil Type: C (Web Soil Survey)

*Due to development at the campus, this site no longer exists.

Figure 12: Bioretention area at The University of Utah.

This bioretention area is one of two bioretention areas constructed by The University of Utah for research purposes in the Spring of 2012 to determine if bioretention is a feasible option in Utah's semiarid climate (Heiberger, 2013).

Its contributing drainage area consists of the adjacent parking lot that sheet flows to a catch basin (Figure 12). Upon reaching the catch basin, flows are conveyed through a 15" plastic pipe to a forebay that is approximately 20 square feet. The forebay then discharges to the bioretention area which contains an overflow outlet structure.

The bioretention area is approximately 1100 sf and has a depth of 4 ft. There are two layers within the bioretention area: the top layer is 2 feet of native backfill soil; the bottom layer is 2 feet of a subsurface reservoir layer composed of Utelite 3/8" medium grade aggregate with a porosity of 53%. Utelite aggregate was selected due to its filtering and planting applications. The reservoir layer allows for storage of up to 1130 cubic feet. Porosity and storage of the topsoil was not reported.

Native species of vegetation were selected to further the applicability of bioretention within the Salt Lake valley's semiarid climate. Common names of selected vegetation include: Curleaf Mountain, Beechleaf Mountain, Little Bluestem Grass, Blue Grama Grass, Indian Grass, Rubber Rabbitrush, Saltbush, Big Sagebrush, Rabbitbrush, Mountain Beebalm, Firecracker Penstemon, and Prince's Plume.

The goals of the site were to determine volume reduction and infiltration rates during storm events. This was accomplished with an array of meters of and sensors placed throughout the bioretention area.

The date, precipitation depth, and total inflow of four notable storms are summarized below.

Storm Event Date	Precipitation (in)	Cumulative Inflow (cf)
8/31/12	0.27	1041
9/1/12	0.15	743
9/25/12	0.21	800
10/12/12	0.79	8165

Figure 13 shows the water level readings during the largest storm event that occurred on 10/12/12. The water depth was measured to be above 4 feet (note the chart's unit is meters) which indicates that the bioretention area was at capacity. This is consistent with the visual findings of debris trails near the inlet.

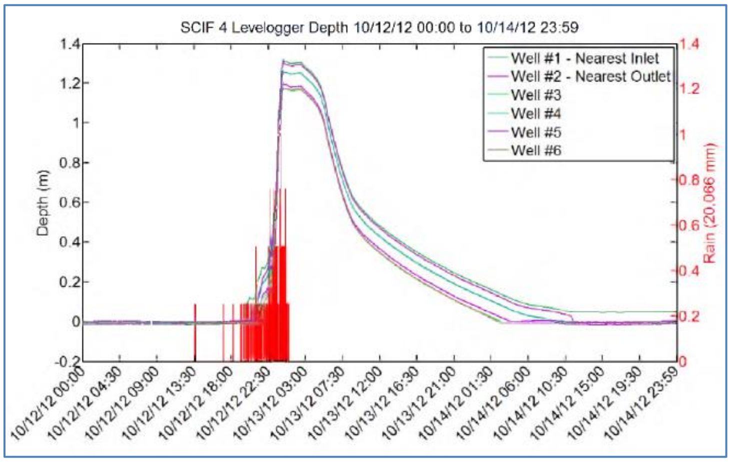


Figure 13: Depth of water within bioretention area.

Six wells were created in which dataloggers were placed to measure average infiltration rates. During the 10/12/12 event, infiltration rates within the bioretention area ranged from 1.42 in/hr to 1.77 in/hr. The range of average infiltration rates for the four storm events is summarized below.

Storm Event Date	Precipitation (in)	Cumulative Inflow (cf)	Infiltration Rate (in/hr)	
			Min	Max
8/31/12	0.27	1041	0.01	0.22
9/1/12	0.15	743	0.19	0.20
9/25/12	0.21	800	0.39	0.98
10/12/12	0.79	8165	1.42	1.77

It is worth noting that the nearest rain gage to this site with a reliable historical record is found at the Salt Lake City airport. The 90th percentile storm depth at that site is approximately 0.58". Using the Reese method of determining the runoff coefficient, the water quality volume for this drainage area would be 2922 cf. Assuming a porosity of 0.25 for the native backfill, the bioretention area would have a total storage capacity of 1684 cf, which would be undersized for the water quality volume.

As part of this research effort, an additional site was created at Mountview Park in Cottonwood Heights. Although analysis during rain events was not performed, it is currently still functioning. A summary and description of the site is given below.

Bioretention **Mountview Park – Cottonwood Heights**

Location: 40.6274°, -111.8449°

Contributing Drainage Area: 18.86 ac

Imperviousness: 64.87% (approx.)

Bioretention Footprint: 2470 sf

Soil Type: A (Web Soil Survey)

Figure 14: Bioretention area at Mountview Park.

Although there was no data analysis of the bioretention area at Mountview Park (Figure 14), the subsurface layers and vegetation selection are similar to the University of Utah site (the storage layer was ¾" Utelite aggregate instead of 3/8"), and with the known information, it can be determined if the site is sized to provide retention for the 90th percentile storm event.

The nearest rain gage with reliable historical data is the Salt Lake Triad Center rain gage. Its 90th percentile storm depth is 0.63". Using the Reese method of determining the runoff coefficient and assuming that the residential areas have an imperviousness of 0.60, the water quality volume for this drainage area would be 24580 cf. Assuming a porosity of 0.25 for the native backfill, the bioretention area would have a total storage capacity of 2620 cf, which would be undersized for the water quality volume. If the subsurface layers remained at a total depth of 4 ft, the footprint would need to be increased to 15760 sf.

Location: 40.5924, -111.9091

Contributing Drainage Area: ac 90th

Imperviousness: 93.9%

Soil Types: C & D (Web Soil Survey)

90th Percentile Storm Depth: 0.77"

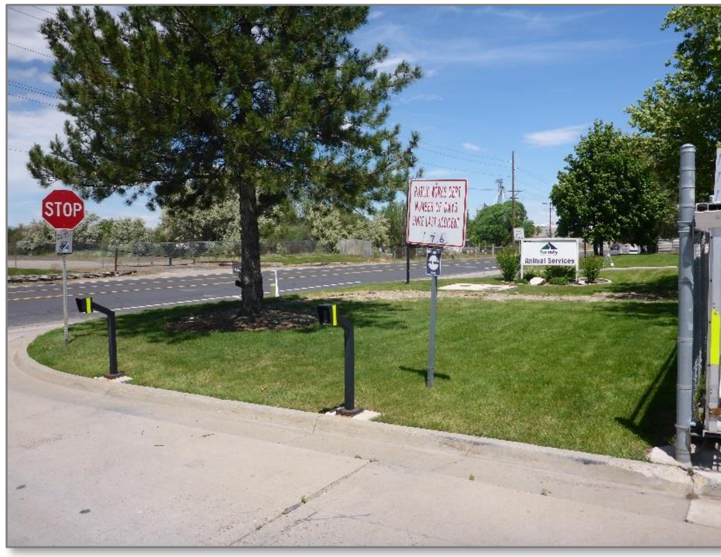


Figure 15: Proposed rain garden location.

In the winter of 2017, 60% of the Sandy City Public Works facility was destroyed by a large fire. Office and administration space, half of the storage area for streets and fleets, and 11 ten-wheel plows were destroyed. Sandy City decided to do a full redesign and take a multi-phased approach to rebuilding the entire site. Construction is currently ongoing (Figure 15).

An LID approach to the site was incorporated into the design and several LID features such as bioswales, rain gardens, and bioretention cells were designed. The Granato method of determining the runoff coefficient ($R_V = 1.14i - 0.371$ when $i > 55\%$) was used (Taylor & Barrett, 2014) and the project's total volume retention goal was 15,600 cf. Due to various infeasibilities and to maintain the functional purpose of the site, it was not possible for the proposed BMPs to capture the full retention volume. Some drainage areas within the site were unable to retain any storm water. Shallow groundwater and poor soils limited infiltration opportunities and it was decided that all bioretention areas would have impermeable liners and underdrain systems. For this reason, all retention BMPs were designed as detention devices with outlet structures connecting to the storm drain network to release within an acceptable drawdown time.

A full list of the site's BMPs and a few characteristics of each is given in the table below.

Table 5: LID BMP characteristics designed for the Sandy City Public Works facility.

LID BMP Type	Subsurface Sections	Underdrain	Drainage Area (ac)	WQV (cf)	BMP's Storage Volume (cf)
Rain Garden 1	Engineered Soil Coarse Sand Pea Gravel Open Graded Stone	Yes	0.34	737	737
Bioswale 1	Engineered Soil	Yes	0.07	141	27
Bioswale 2	Engineered Soil	Yes	1.23	2309	1469
Rain Garden 2	Engineered Soil Coarse Sand Pea Gravel Open Graded Stone	Yes	0.15	280	280
Bioswale 3	Engineered Soil	Yes	0.42	800	366
Rain Garden 3	Engineered Soil Coarse Sand Pea Gravel Open Graded Stone	Yes	0.41	885	541
Vegetated Swale	Native backfill	No	0.65	1291	140
Concrete Pavers	AASHTO No. 8 AASHTO No. 57 Drain Rock	Yes	0.13	55	55
Permeable Asphalt	AASHTO No. 8 AASHTO No. 57	Yes	0.13	55	55
			Total Volume (cf)	6553	3670

Four of the nine BMPs were able to be sized for their water quality volume resulting in 56% of the total water quality volume of all BMPs. Although the volume retention goal for the entire site was 15,600 cf and all drainage areas were evaluated for their retention potential, many of the drainage areas were deemed to be infeasible for various reasons. Lack of available open space, constraints imposed by the downstream storm drain network, and groundwater restricted five of the BMPs from being able to be sized for the full water quality volume.

Figure 16: Construction progress of permaculture garden.

Location: 38.5700°, -109.5526°

Soil Type: C

In 2014, as part of a campus-wide landscaping redesign, it was decided that portions of the parking areas of Utah State University Moab would undergo a renovation to capture rainfall and create a thriving, productive micro-riparian area. With the removal of a few parking spaces and the conversion of previously unused impervious areas, two permaculture gardens were created that now support vegetation and are aesthetically pleasing areas that benefits the public while retaining rainfall that is reintroduced to the soil instead of conveying directly to catch basins. Each garden contains bioretention systems and bioswales (Figure 16) that collect runoff from the adjacent parking lots and down drains from nearby buildings.

Although the permaculture garden was not specifically designed for targeted pollutants, it's worth noting that the garden is located just over one mile away from the Colorado River at the confluence of Mill Creek and Pack Creek. Both creeks are listed for 303(d) impairments including dissolved oxygen, E. coli, dissolved selenium, temperature and total dissolved solids. A monitoring program would reveal the effectiveness of the bioretention and bioswales at removing these pollutants.

The nearest rain gage with a reliable historical record is Arches National Park HQS, which has a 90th percentile storm depth of 0.53". With an estimated contributing drainage area of 1.0 acre, all of which is impervious area (Reese runoff coefficient = 0.89), the volume retention goal for the permaculture garden would be 1710 cf.

Additional Local LID Implementation

Daybreak, South Jordan

Daybreak is a mixed-use development located in South Jordan, Utah in the southwest corner of Salt Lake County. The area for the development was formerly surplus mining land and is planned to contain more than 20,000 residential units.

A variety of techniques were used to mitigate the effects of urbanization on storm water runoff quality. Among the LID techniques used in the community are bioswales, dry wells, constructed wetlands, infiltration trenches, infiltration basins, and detention basins. The community also stipulates that 40% of residential lots and 68% of common open spaces consist of native, drought resistant plants. This strategy is designed to be able to retain the 100-year storm event.

Researchers conducted a water quality monitoring study on the development to determine the effectiveness of the green infrastructure design. One sub-watershed utilized a series of bioswales while the other sub-watershed deployed traditional storm water management techniques. Several constituents were monitored for water quality including nitrogen, phosphorus, suspended solids, and heavy metals. The sub-watershed with bioswales showed significantly reduced runoff volumes as well as large reductions in constituent and heavy metal concentrations when compared to the traditional storm water sub-watershed. A promising finding of the study was that concentrations of copper were reduced by 82%, which is significant due to its removal difficulty and the proximity of copper mines in the area. (Yang, Li, Wall, Blackmore, & Wang, 2015)

Green Meadows, Logan

The Green Meadows subdivision is in Logan, Utah near 600 South and 1250 West. The subdivision is a relatively new settlement with houses first being constructed in the early 2000's according to Google Earth imagery. The western end of the subdivision borders the Logan River which is in the Lower Bear River watershed. A water quality management plan was established for the watershed in 1995 and found that the Logan River had relatively good water quality after they passed through Cache Valley. As of 2016 was listed on 303d report by the Utah DWQ as having impairment for total phosphorus with a TMDL approved by the EPA.

Utah State University used the subdivision for a case study on the effectiveness of vegetative species within bioretention cells. The study focused on biomass production and water quality improvement to measure the effectiveness of the vegetation. Laboratory tests were conducted with simulated frequency and duration rainfall events to measure biomass production and pollutant removal. Field tests were conducted at the site to generate water quality improvement effectiveness data. Citric acid was added at the field site to simulate a possible increase in nutrient and metal uptake.

The USU study found that common reed and sedges were optimal plants for the area to improve storm water quality. The field site showed significant retention and infiltration capacities throughout the study and 100% pollutant removal from storm water runoff. Maximum nutrient and metal removal was shown to be possible at the site if there was no discharge from the bioretention cells. In tests with added citric acid, metal solubility was increased in the water but no significant metal uptake was observed. (Dupont & McLean, 2018)

LID BMPs

Introduction

LID BMPs are long-term structures, graded features, or practices that are designed to retain and/or treat runoff close to its origin after construction is complete. Guidance is given in the following areas:

- **Fact Sheets:** The following sections are discussed either within the preface to the fact sheets or within the fact sheets: pollutant removal effectiveness, design criteria, calculation methods, sample calculations, evaluating BMP effectiveness, technical infeasibilities, water quality concerns, a designer checklist, vegetation selection, installation, installation costs, maintenance, maintenance activities, maintenance costs, and a cross-sectional figure.
- **Treatment Trains:** A description of the use and benefits of treatment trains.
- **Proprietary Devices:** Manufactured devices that have been designed specifically for storm water quality.
- **LID BMP Selection:** How to use 303(d) listed impairments, TMDLs, and land use to select BMPs. Three flow charts for BMP selection based on site conditions and design criteria.
- **Vegetation Selection:** Description of the role of vegetation and guidance on plant selection for BMPs.
- **Land Use Examples:** Hypothetical developments showing a site plan for residential, commercial, and industrial land uses and how an LID approach improves the storm water quality benefits.

LID BMP Fact Sheets

The DWQ has developed fact sheets for 11 LID BMPs. They can be found in Appendix B.

LID BMP Type	Fact Sheet ID	LID BMP Category
Rain Garden	BR-1	Bioretention
Bioretention Cell	BR-2	
Bioswale	BR-3	
Vegetated Strip	BR-4	
Tree Box Filter	BR-5	
Green Roof	BR-6	
Pervious Surface	PS-1	Pervious Surfaces
Infiltration Basin	ID-1	Infiltration Devices
Infiltration Trench	ID-2	
Dry Well	ID-3	
Underground Infiltration Devices	ID-4	
Harvest and Reuse	HR-1	Harvest and Reuse

Where possible, information that is relevant to all BMPs has been summarized below in this preface instead of repeating identical information in each fact sheet.

Preface to Fact Sheets

Pollutant Removal Effectiveness

The reported pollutant removal effectiveness is determined from various sources and provides general guidance. Many factors contribute to a BMP's pollutant removal effectiveness such as climate, vegetation selection, and maintenance practices. Analysis of monitoring data is the only definitive method of determining actual pollutant removal for any BMP. (Taylor & Barrett, 2014; Filterra Bioretention, 2018; Minnesota Pollution Control Agency, 2018; WERF, 2016; Charlesworth, Beddow, & Nnadi, 2017)

Design Criteria

The design criteria for each BMP are based on generally accepted designs. The maximum and minimum ranges are meant to provide a starting point for permittees to develop their own standards, details, and designs. They are not prescriptive. Deviation from the design criteria in these fact sheets is acceptable and encouraged if alternative designs are supported by sound engineering practice, research, or have been shown through past implementation to be effective.

Calculation Methods

BMPs are sized for the water quality volume and/or the water quality flow of the BMP's contributing drainage area. The following equations are used for the BMPs in the fact sheets.

Manning's Equation

Applicable BMPs: Bioswale, Vegetated Strip

$$Q = \frac{1.49}{n} A R^{\frac{2}{3}} \sqrt{S}$$

Where:

Q = Flow rate, cfs

n = Manning's roughness coefficient, unitless

A = Cross-sectional area of flow, sf

R = Hydraulic radius, sf/ft

S = Longitudinal slope, ft/ft

Continuity Equation

Applicable BMPs: Bioswale, Vegetated Strip

$$Q = AV$$

Where:

Q = Flow rate, cfs

A = Cross-sectional area of flow, sf

V = Flow velocity, ft/s

Storage volume within a media with a known porosity

Applicable BMPs: Rain Garden, Bioretention Cell, Pervious Surfaces, Infiltration Basin, Infiltration Trench

$$V_{storage} = nV$$

Where:

$V_{storage}$ = Volume of runoff available for storage within media, cf

n = Media porosity, unitless

V = Volume of media layer, cf

Drawdown time

Applicable BMPs: Rain Garden, Bioretention Cell, Pervious Surfaces, Infiltration Basin, Infiltration Trench

$$t = \frac{(D_T n_W + d)}{k}$$

Where:

t = Drawdown time, hrs

D_T = Total depth of soil matrix, in

n_W = Weighted average porosity of soil matrix based on soil layer depth

d = Ponding depth, in

k = Infiltration rate of soil matrix, in/hr

Minimum footprint area

Applicable BMPs: Rain Garden, Bioretention Cell, Infiltration Basin, Infiltration Trench

$$A_{min} = \frac{12xSFxWQV}{kt}$$

Where:

12 = Conversion factor (inches to feet)

SF = Safety factor

WQV = Water quality volume, cf

k = Infiltration rate, in/hr

t = Drawdown time, hr

Water quality outlet elevation

Applicable BMPs: Rain Garden, Bioretention Cell, Infiltration Basin

$$Ele_{WQ} = \frac{WQV}{A_{bottom}}$$

Where:

Ele_{WQ} = Elevation of the water quality volume above basin bottom where overflow is provided, ft

WQV = Water quality volume, cf

A_{bottom} = Area of basin bottom, sf*

*Although stage storage calculations may determine the water quality elevation, using the basin bottom will yield a conservative value.

Sample Calculations

The sample calculations provide one working configuration of a planning level design for each type of BMP. For example, the sample calculations in the rain garden fact sheet assume that the soils infiltrate and that there are no subsurface constraints. However, if a rain garden is required to be lined, an underdrain design and detention time will have to be considered. Different approaches beyond what is shown in the examples might be required and alternate calculation methods are acceptable if they are supported by sound engineering practice, research, or have been shown through past implementation to be effective.

The samples use hypothetical permittee requirements and design criteria for the purpose of showing their role in BMP design. An example may state that the permittee requires 6 inches of freeboard for a BMP, but permittees are encouraged to develop and implement their own design standards.

The examples have been prepared with the assumption that the BMPs are for water quality purposes only. It is assumed that upstream bypasses have been provided for larger storm events or that overflow structures within the BMP are provided. All examples use the Reese runoff coefficient (See: Developing the 90th Percentile Volume).

Evaluating BMP Effectiveness

To evaluate the performance of a BMP, it is necessary to know its purpose for the developed site and to understand the goals of the BMP's watershed. Visiting BMPs during storm events is a highly valuable method for determining if the BMP is functioning as expected. If the BMP is part of a monitoring program, analysis of monitoring data will reveal if it is performing as expected.

There are many general questions that can be applied to all BMPs to gain a basic understanding of whether the BMP is functioning properly and performing as expected and meeting its goals.

Site-Specific Considerations

1. Are flows reaching the BMP?
2. Is standing water present at or upstream of the BMP?
3. Is sediment collecting at the upstream end before entering the BMP?
4. Does the BMP overflow during large storm events?
5. Have changes to the site altered the quantity or quality of runoff that drains to the BMP?
6. Is the BMP within a permittee's database and is it being regularly maintained by the responsible party?
7. Has the public raised concerns about the BMP?

Watershed Specific Considerations

1. Is the BMP located within a 303(d) listed watershed and does the watershed have an approved TMDL?
2. Was the BMP designed to address specific TMDL approved impairments?
3. Has upstream and downstream monitoring equipment been set up for the BMP and is it functioning?
4. Does monitoring data show that targeted pollutants are being removed?

Answers to these questions will indicate whether the BMP is functioning as expected and provide guidance on how to remedy any functionality or treatment issues that arise. Additional considerations specific to each BMP are found within the fact sheets.

Technical Infeasibilities

It may be technically infeasible to install BMPs at the project site. Technical infeasibilities will be related to soil conditions, available right-of-way, economic factors, or other reasons. Possible technical infeasibilities have been categorized below by BMP type.

General Infeasibilities

- Insufficient right-of-way
- Inadequate maintenance access
- Public safety concerns or BMP is unable to be designed in a way that is compatible with permittee's safety standards
- Insufficient head to allow for proper BMP drainage
- Utility conflicts that can't be resolved

Bioretention/Infiltration/Detention

- High groundwater that does not allow for the minimum separation between the bottom of the BMP and the water table
- Poorly infiltrating soils (though detention may still be an option with an impermeable liner)
- Proximity to structures (though detention may still be an option with an impermeable liner)

Pervious Surfaces

- If pervious surface would not provide sufficient load bearing strength for heavy loads
- If storage beneath pervious surface would threaten the stability of adjacent subgrades

Harvest and Reuse

- There are no opportunities for reuse within the contributing drainage area
- Harvest and reuse system cannot be practically designed without significant impact on the project

Water Quality Concerns

General Concerns

Negative impacts on water quality from the construction and existence of LID BMPs can generally be avoided in the development's design phases. On the planning level, water quality degradation can be avoided by considering the proximity of BMPs to environmentally sensitive areas such as landfills, areas with known groundwater contamination, and wellhead protection areas: retention at these locations is not advised as it has the potential to mobilize contaminated groundwater and worsen down-gradient groundwater or drinking water. Installing BMPs without consideration to geotechnical conditions such as high groundwater and poor soils can lead to a failed BMP that results in degraded water quality that in turn interacts with groundwater and receiving waters. Compaction of soils at the bottom of a BMP or within a soil matrix that are meant to infiltrate will likely result in standing water, vector issues, or algae. Poorly maintained BMPs will result in many possible modes of failure such as standing water, vector issues, algae, flooding, failed soils, or other issues which will compromise the integrity of groundwater or adjacent receiving waters.

Designer Checklist

The designer checklist may be used by those who are designing or reviewing the design decisions that were made for each BMP. Engineering judgment should be used for all design decisions and LID approaches. Consider including information from the designer checklist in the Storm Water Quality Report.

Vegetation Selection

The percent of vegetative coverage has a direct impact on the pollutant reduction performance of the BMP. During a 2-year monitoring study of roadside vegetation by the Caltrans Division of Environmental Analysis, it was found that a minimum coverage of at least 65% was needed for pollutant reduction to occur but that there was a significant decrease in pollutant reduction below 80% (CALTRANS Division of Environmental Analysis, 2003). This result is consistent with similar studies that have led to minimum vegetative requirements for various permittees nation-wide that range from 65% to 80%.

A plant selection matrix containing appropriate trees, grasses, shrubs, and groundcover for the LID BMPs covered in this manual is provided in Appendix D.

The following should be considered in selecting vegetation for all BMPs:

- Vegetation is adapted to the local climate, considering seasonal temperature ranges and average rainfall, (exposure to direct sun, frost, wind) and desired irrigation
- Tolerant of weather conditions at the specific site such as extreme high and low temperature (Appendix X contains a matrix of example plants that could be used in each of Utah's climate zones with each BMP), strong winds, sun, and snow.
- Tolerant of varied moisture conditions (wet and dry).
- Adaptable to varying soil types and conditions.
- Non-invasive species for area and site conditions (will not readily spread by air, seed transport, or root invasion).
- Resistant to wildlife foraging such as deer, elk, and rabbits and local pests and diseases.
- Habitat value and linkages in urban environments to larger open spaces on the fringe of urban development.
- Maintenance requirements (e.g., invasive root growth, pruning, thinning, dead-heading) and site accessibility.
- Adherence to local design criteria such as height limitations and approved plant lists.
- Available in local or regional nurseries.
- Attractive appearance.

Bioretention/Bioswales/Infiltration/Detention

Typically, bioretention BMPs receive greater pollution due to storm runoff from streets and roadways; and these BMPs receive water after every storm event. As a result, they require plants that:

- Have a greater ability for nutrient uptake and pollutant neutralization.
- Can survive in boggy and moist soils.

- Tolerate de-icing agents.

Infiltration Basins

Infiltration basins generally hold water for longer periods of time; however, only the bottom of the basins hold the standing water. Plants located in the bottom of the basin must be able to tolerate standing water for several days, while plants located on the side slopes must be able to tolerate drier conditions. Select plants in infiltration basins that:

- Withstand being covered with water for a few days to possibly a week or more.
- Reduce the need for supplemental irrigation and maintenance.
- Do not require additional fertilization and thereby reduce polluted runoff potential.

Vegetated Strips

Vegetated strips are typically small and have limited planting space, so selection must consider the overall size in conjunction with safety requirements. Select plants that:

- Do not require additional fertilization and thereby reduce polluted runoff potential.
- Tolerate environmental factors such as reflective pavements and building materials, de-icing agents, and air pollution at the site.
- Withstand trampling and vandalism in urban conditions.

Green Roofs

See the Green Roof fact sheet for specific information relating to vegetation selection for green roofs.

Installation

LID BMPs should be taken offline during construction so that flows within its drainage area do not enter the BMP until construction is complete. They should not be used as construction BMPs.

Typical installation activities for each BMP can be found within each BMP fact sheet.

Installation Costs

Refer to each BMP fact sheet for a general list of construction items. Costs will vary.

Maintenance

Proper maintenance will significantly improve the functionality of the BMP and increase its life span. Maintenance activities typically include semiannual inspections but may be required more often such as shortly after construction, after qualifying storm events, or on an as needed basis. Documentation of maintenance activities is encouraged to provide a record of inspection frequency, maintenance activities, and associated costs.

Maintenance agreements between the permittee and the final owner of the BMP (if not the permittee) should identify key maintenance elements such as: transfer of BMP ownership; a description of maintenance activities and who is expected to perform them (owner, permittee, other); a method of resolution should violation of the maintenance agreement occur.

A description of typical maintenance considerations for each BMP type is given below.

Bioretention/Infiltration/Detention/Harvest and Reuse

- Inspect for and remove trash and debris.
- Inspect for sediment buildup or pollutant accumulation within or upstream of BMP. Remove if necessary.
- Determine cause of any standing water within BMP and remediate.
- Ensure that vegetation is established.
- If underdrains have been installed, ensure that they are functioning properly.
- If irrigation system has been installed, ensure that it is functioning properly.
- For green roofs, additional inspection of the roof structure may be required.

Pervious Surfaces

- Inspect for clogging of pervious surfaces. Power wash if necessary.
- Inspect for depressions. Depressions will indicate that the subsurface layers are failing or have failed. Regrading may be required.

Maintenance Activities

Detailed descriptions of maintenance activities, inspection frequencies, actions that can be taken to resolve maintenance issues, and the general level of effort associated with maintenance activities can be found in each BMP fact sheet.

In determining the inspection effort, the following descriptions were used:

> *Low* – Visual inspection only required to make determination of possible required maintenance activity.
>
> *Medium* – Visual inspection and other physical activity is required, such as opening an observation or a manhole lid; or, visual inspection and training is required, such as identifying invasive species, to make determination of possible required maintenance activity.
>
> *High* – Visual inspection, physical activity, and training is required to make determination of possible required maintenance activity.

Maintenance Costs

Maintenance costs are tied to maintenance activities. Inspection of BMPs requires either an onsite presence that is tasked with performing the inspections or a designated person or persons who must visit the BMP to perform the inspection. In either case, the inspector(s) will need to be trained to make correct determinations of the next maintenance activity (if any) for any given maintenance issue that is required to remedy a failing or poorly maintained BMP (Figure 17). Permittees are encouraged to track maintenance activities and costs.

In general, the following items are taken into account when considering maintenance costs: inspection frequency, inspection duration, crew size, machinery costs, and remediation. Remediation costs will vary widely based on the action required.

Figure 17: Standing water after a rain event at a bioretention BMP.

The following table summarizes various studies that evaluated LID maintenance costs (Mark Grey, 2013). Values have been adjusted from their original sources for inflation to reflect estimated 2018 dollars. Actual costs will vary, perhaps significantly, based on local practice. However, it typically holds true that vegetated strips are the cheapest BMP to maintain while green roofs are the most expensive. Rain gardens, pervious surfaces, and infiltration devices tend to fall within average ranges depending on the size of the BMP. Maintenance costs for harvest and reuse are not given and will vary by use but tend to be very low; costs for devices such as rain barrels will include visual inspection and possible replacement of the device.

Table 6: Estimate of costs for maintenance activities.

BMP Type	Cost/Acre of Contributing Impervious Area	Cost/SF of BMP		Cost/100 Linear Feet/Year	Cost/CF		Source
		Low	High		Low	High	
Bioretention (Rain Garden, Bioretention Cell)	$2,200	$3	$19	-	-	-	
Bioswale	$1,000	$1	$47	$415	-	-	
Vegetated Strip	-	-	-	$21	-	-	
Flow-Through Planter (Tree Box Filter)	-	$30	$79	-	-	-	
Green Roof (Extensive)	-	$8	$372	-	-	-	
Green Roof (Intensive)	-	$18	$597	-	-	-	
Pervious Asphalt/Concrete	$1,200	$3	$27	-	-	-	
Reinforced Grass/Joint Pavers	-	$2	$27	-	-	-	
Infiltration Basin	-	-	$17	-	-	-	
Infiltration Trench	-	$16	$49	$415	-	-	
Dry Well	-	-	-	-	$6	$12	

Figures

The figures for each BMP show a general cross-section that is a starting point for site-specific design. Use of these figures is appropriate for planning level design. For project design, the level of detail, the layout, and cross-sections for the selected BMPs should meet the permittee's CAD and design standards and include all information required for construction.

Treatment Trains

Treatment trains are a configuration of BMPs in series designed to achieve a pollutant reduction goal or a volume retention goal. Treatment trains are commonly used when a BMP is able to provide pretreatment to a downstream BMP. An example of this is shown in Figure 18 where a swale has been designed to provide pretreatment for the dry well. Another scenario where a treatment train may be appropriate is when additional BMPs are needed to be able to adequately provide volume retention. A scenario where this is possible is a site where insufficient right of way exists for a rain garden that is large enough to retain the entire water quality volume, but there is available right of way for an upstream bioswale that can provide additional retention. Site design practices can also be part of a treatment train (WEF Press, 2012).

Figure 18: A vegetated swale that will provide pretreatment for a dry well.

When the treatment train results in keeping runoff onsite, it has been found to more effective. For this reason, BMPs that allow for physical, chemical, and biological processes are good candidates for treatment trains as these processes occur within BMPs that are designed to capture runoff. The majority of pollutant reduction occurs within the most upstream BMP. This is attributed to the theory of irreducible pollutant concentrations. Irreducible pollutant concentrations occur because of the BMP's inability to adsorb and degrade pollutants beyond a certain concentration (Schueler, 2000).

Treatment train configuration should be considered carefully based on the water quality goals and targeted pollutants at the site. Treatment train configurations are unlimited. Common configurations based on the LID BMPs discussed in this manual are shown in Figure 19.

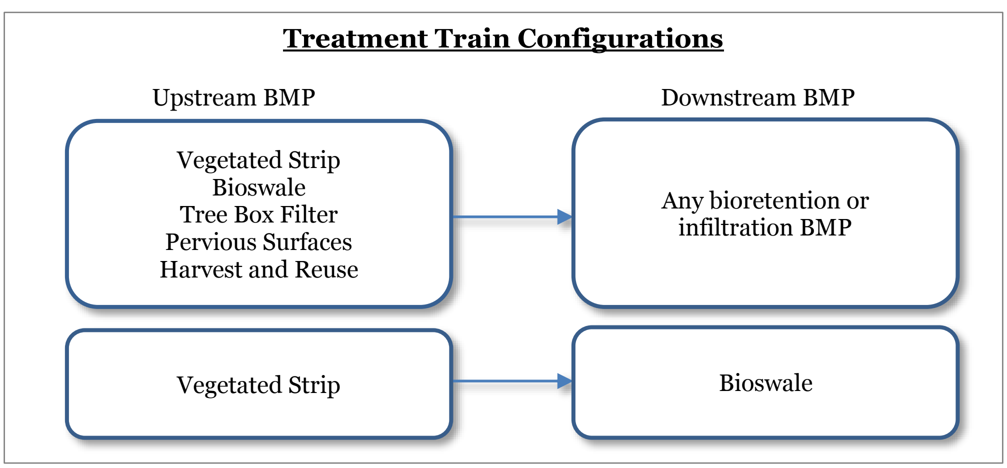


Figure 19: Common treatment train configurations.

Proprietary Devices

Figure 20: Proprietary tree box filter.

Proprietary devices, such as tree box filters (Figure 20), media filters, and underground chambers use proprietary designs, soil mixes, aggregates, and other technologies to accomplish volume retention and storm water treatment.

Consideration of proprietary devices, as with other LID BMPs, should occur at the planning level. These devices serve well in highly urbanized areas where there is limited room for other treatment options. Drainage areas with high imperviousness will require that the device have a larger footprint. A common design criterion for the size of the proprietary devices is the flow-through rate and are often referred to as flow-through devices.

These devices and technologies are typically designed with the help of the manufacturer. An approved list of vendors, devices, or other technologies may be written into a permittee's storm water management plan. Manufacturers will also be able to provide maintenance activities and inspection frequencies associated with the device. Discussion of specific proprietary devices within this manual does not constitute an endorsement of the device; nor does exclusion of a device constitute a lack of endorsement. Permittees are responsible for determining which devices and technologies to use within their jurisdiction at the planning or project level.

Tree Box Filters
Tree box filters are typically contained within a concrete vault if being designed as a flow-through device. The vault bottom is removed if it is decided that infiltration is an appropriate function of the filter. See the Tree Box Filter fact sheet for additional information.

Underground Detention or Retention
Underground systems, such as chambers, are installed beneath project surfaces that already serve a function, such as parking, when there is limited space within the project limits to provide above ground detention or retention. These systems are designed for flood control volumes or they are specifically designed for the 90^{th} percentile volume.

Others
Soil mixes, aggregate composition, concrete pavers, pervious concrete mixes, and permeable asphalt mixes are all examples of types of proprietary devices and technologies. Permittees are encouraged to seek out and determine which devices are appropriate for their projects.

LID BMP Selection

Selection of BMPs is based on many factors. At the planning level, receiving waters, 303(d) impairments, TMDLs, land use, and watershed management plans will play a role in determining which BMPs are most appropriate. At the project level, right of way, groundwater, contaminated soils or groundwater, poorly draining soils, and connections to the storm drain network are all variables that will guide the project team toward BMP selection. The following sections provide tables and charts that can be used to assist in the selection of appropriate BMPs.

BMPs Categorized by 303(d)/TMDL

The following table summarizes pollutants that are currently either 303(d) listed as having impairments or that have approved TMDLs within at least one watershed in Utah along with BMPs discussed in this manual that are rated either 'Medium' or 'High' for pollutant removal effectiveness for the given category. BMPs are not identified for categories in which pollutant removal effectiveness is not rated.

Table 7: BMP types rated for the removal of pollutants that are either 303(d) listed or have approved TMDLs within Utah.

Pollutant	Category	BMP Type
E. coli	Bacteria	All but bioswales and pervious surfaces
Total Coliform		
Dissolved Oxygen	Dissolved Oxygen	-
Total Dissolved Solids	Dissolved Solids	-
Cadmium	Metals	All
Zinc		
Aluminum, Dissolved	Metals (Dissolved)	All
Arsenic, Dissolved		
Cadmium, Dissolved		
Copper, Dissolved		
Iron, Dissolved		
Lead, Dissolved		
Mercury, Dissolved		
Zinc, Dissolved		
Ammonia	Nutrients	All but bioswales and green roofs
Boron		
Boron, Total		
Nitrate as N, Total		
Selenium		
Selenium, Dissolved		
Total Ammonia		
Total Phosphorus		
OE Bioassessment	OE Bioassessment	-
pH	pH	-
Gross Alpha	Radioactivity	-
Radium		
Sediment	Sediment	All
Temperature	Temperature	-

BMPs Categorized by Land Use

Residential, commercial, and industrial land uses produce unique and common pollutants. Sediments, pet waste, fertilizers and pesticides are common pollutants in residential areas. Pollutants in commercial and industrial land uses vary depending on site activities. Landscaping, outdoor storage, metal roofs, food, and animal waste products will determine which pollutants may be expected. Table 8 summarizes expected pollutants by land use.

Table 8: Expected pollutants by common land uses.

Land Uses	Expected Pollutants				
	Sediment	Nutrients	Metals	Bacteria	Oil/Grease
Residential	Y	Y	N	Y	Y
Commercial	N	N	N	N	Y
Industrial	N	N	N	N	Y
Parking Lots, Streets, Highways, Freeways	N	N	Y	Y	Y
Expected for Any Land Use if Landscaping Exists	Y	Y	N	N	N
Expected for Any Land Use if Outdoor Storage or Metals Roofs Exist	N	N	Y	N	N
Expected for Any Land Use if Food or Animal Waste Products are Present	N	N	N	Y	N

Source: Modified from Table 2-1 of the Orange County Technical Guidance Document

Cross-referencing Table 8 with the pollutant removal effectiveness ratings for the BMPs discussed in the fact sheets, specific BMPs that are expected to perform can be identified per land use. The pollutant removal effectiveness for the majority of the BMPs is either 'Medium' or 'High' for the targeted pollutants. For simplicity, appropriate BMP types are either identified as 'All,' meaning that all BMPs are rated 'Medium' or 'High' for the targeted pollutant, or BMPs that are rated 'Low' have been named in the table. Pollutants that are not expected for each land use per Table 8 remain blank. Ultimately, site conditions will determine the potential pollutants at a site and reasonable judgment should be used in BMP selection.

Table 9: Classification of LID BMPs according to their pollutant removal rate, targeted pollutant, and land use.

Land Uses	Targeted Pollutant				
	Sediment	Nutrients	Metals	Bacteria	Oil/Grease
Residential	All	Bioswale and green roof 'Low'	-	Bioswale and pervious surface 'Low'	Green roof 'Low'
Commercial	All	Bioswale and green roof 'Low'	-	Bioswale and pervious surface 'Low'	Green roof 'Low'
Industrial	-	-	-	-	Green roof 'Low'
Parking Lots, Streets, Highways, Freeways	-	-	All	Bioswale and pervious surface 'Low'	Green roof 'Low'
Expected for Any Land Use if Landscaping Exists	All	Bioswale and green roof 'Low'	-	-	-
Expected for Any Land Use if Outdoor Storage or Metals Roofs Exist	-	-	All	-	-
Expected for Any Land Use if Food or Animal Waste Products are Present	-	-	-	Bioswale and pervious surface 'Low'	-

BMP Selection Flow Charts

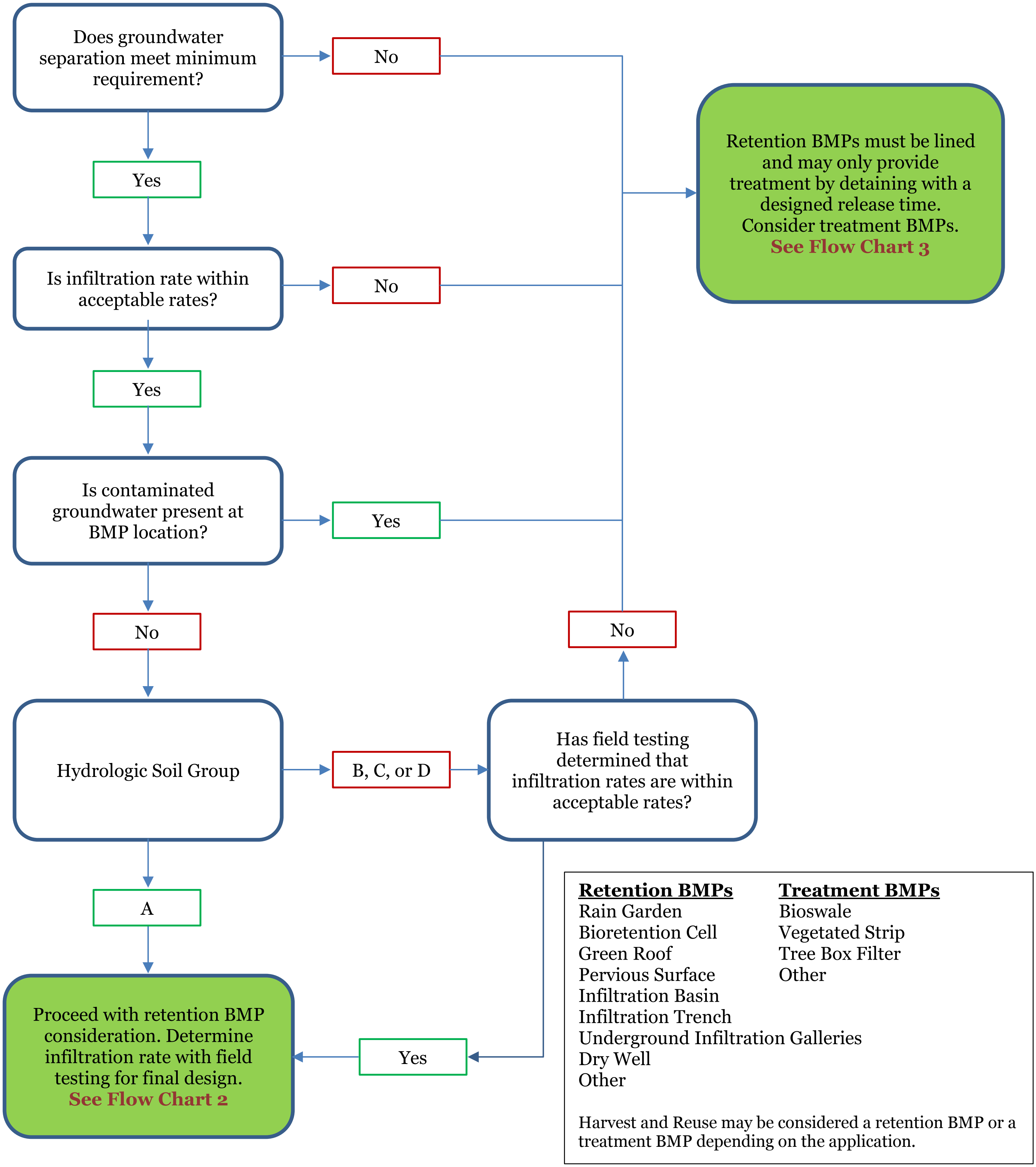
Selection of LID BMPs is determined by site constraints. There may be geotechnical constraints that govern BMP selection that apply to the entire site, such as shallow groundwater or poor soils, which would rule out the possibility of retention BMPs. When retention BMPs cannot be used, treatment BMPs should be considered. Three flow charts have been developed to assist in the selection of appropriate BMPs.

Flow Chart 1: Retention BMP vs Treatment BMP Selection
Based on site conditions, determine if retention or treatment BMPs will be used. Retention BMPs are those that are able to provide volume retention. Treatment BMPs, such as bioswales, vegetated strips, and tree box filters typically do not provide volume retention but are still able to treat runoff.

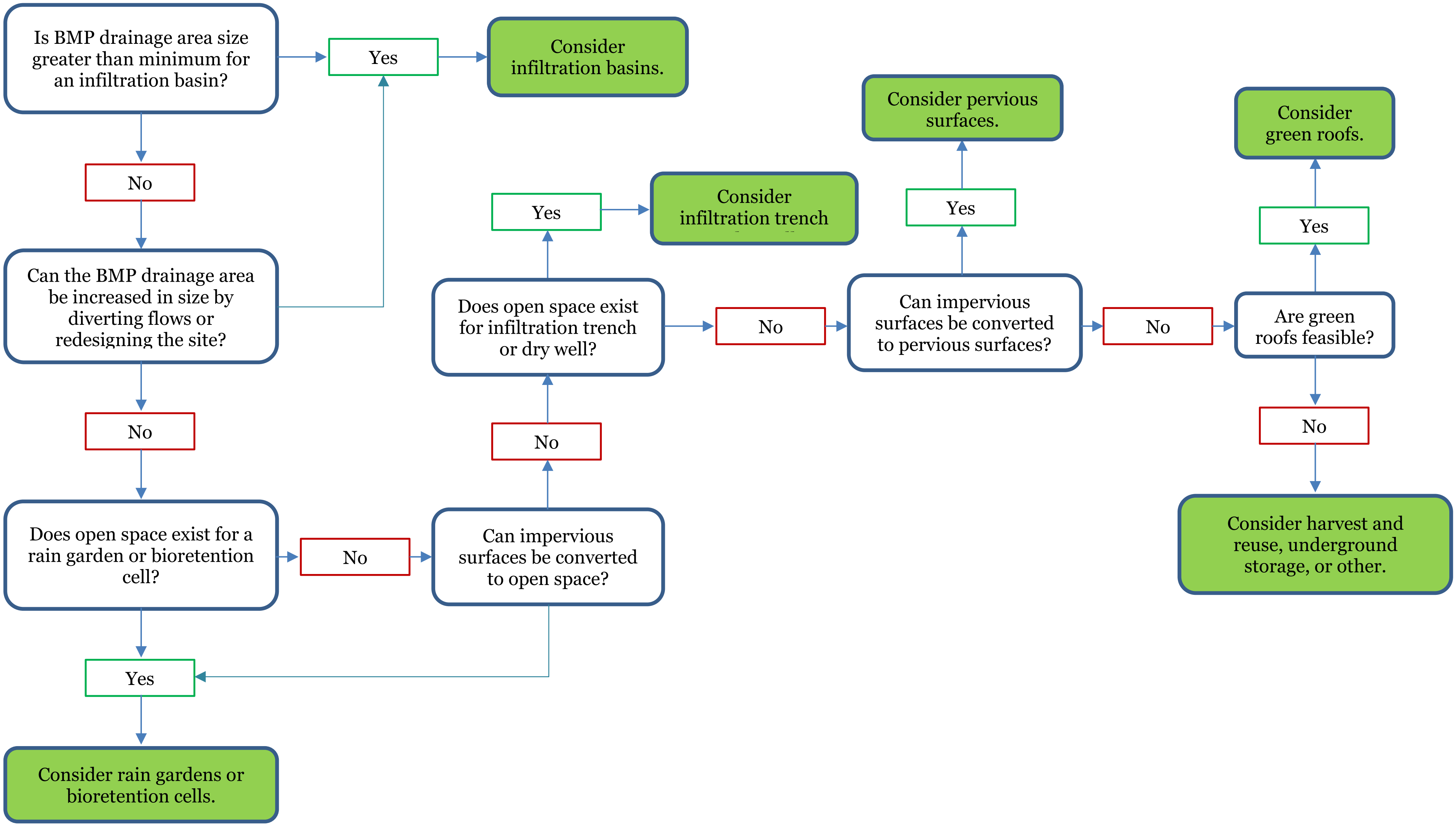
Flow Chart 2: Retention BMP Selection
Determine which retention BMPs are most appropriate based on the design criteria and technical criteria of each retention BMP.

Flow Chart 3: Treatment BMP Selection
Determine which treatment BMPs are most appropriate based on the design criteria and technical criteria of each treatment BMP.

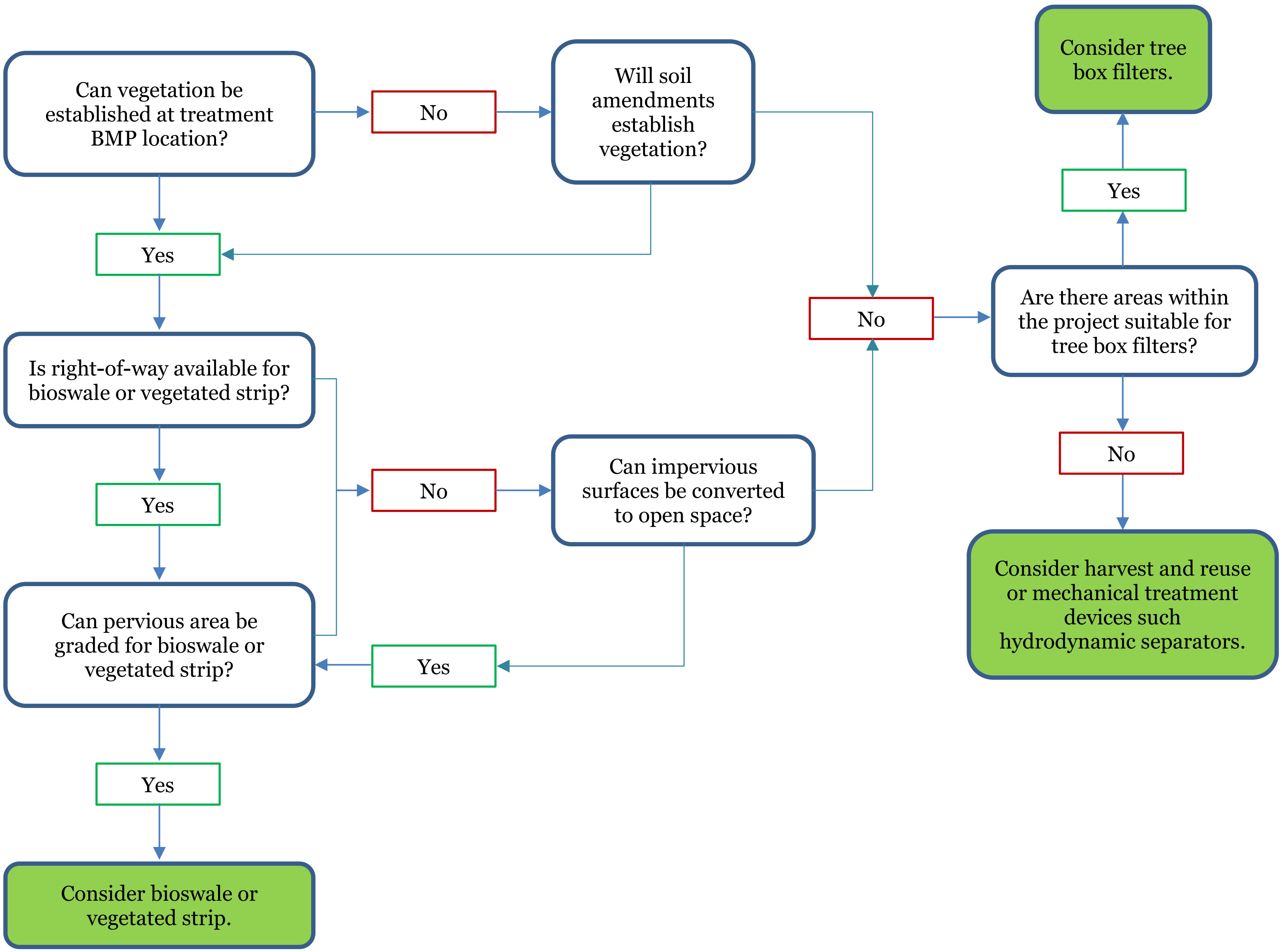
Flow Chart 1: Retention BMP vs Treatment BMP Selection



Flow Chart 2: Retention BMP Selection



Flow Chart 3: Treatment BMP Selection



Vegetation Selection

In choosing both native and non-native plant species for low-impact development, several considerations need to be observed to promote plant health and ability to thrive. Factors that should be considered include: adaptability of plants to the site conditions, water consumption, soil types, heat and cold tolerances, ability to withstand air and soil pollutants.

It is critical to match the needs of the plants to the site conditions both current and future. As the landscape transforms into a built environment the heat index increases and therefore, evapotranspiration rates increase. Furthermore, natural drainage patterns are altered as buildings and associated infrastructure are developed. Therefore, plants selected must be adaptable not only to the current site conditions, but be tolerant of increased shade, heat, reduced air around roots and pollutants.

Water Requirements

In the arid high and low deserts of Utah it is critical that plants are either native or drought tolerant. This not only helps reduce plant stress, but conserves water. Plants that are not well adapted to the region will tend to be more stressed and therefore, require more water, nutrient supplements and overall management. It is important to note that, as plants are stressed, many times fertilizers are used which can increase water pollution. Consideration of the natural habitat of plants and the moisture content in the air of their native habitat it also important. Plants that are not suitable to more arid environments are not the best choice for Utah landscapes.

The soils throughout Utah vary greatly. Some plants prefer growing in consistently moist soils while others prefer dry soil with only intermittent changes in moisture levels. Also, the alkalinity, salinity and soil structure are important factors. For example, plants that tend to do well in dry, shallow, rocky soils with a higher tolerance for salt buildup will tend to do better in rooftop gardens compared to plants that prefer acidic bog-like conditions and are better suited to a bioretention cell or rain garden.

Typically, plants that can tolerate fluctuations in soil moisture are good choices for basins, swales, bioretention cells, rain gardens and tree box filters. Plants with an ability to withstand intermittent standing water are better suited to basin bottoms, bioretention cells, rain gardens and tree box filters, while plants needing good drainage are better suited to basin slopes. Another factor to consider is the soils structure as it impacts the root system of plants. Plants that generally grow shallow surface roots would not be a good choice for areas that may be inundated with heavy flows of surface water while those with taproots and a deeply penetrating root system would be a better choice.

Soil

Plants that have a proven ability to tolerate soil compaction, increased heat and reduced air flow are best suited for landscape strips. Being placed in parking lots and along streets requires plants that can produce strong tap roots in less than ideal conditions, especially for trees which may otherwise blow over in wind gusts.

It is also important to consider the soil in relation to microbes and plant material, especially for tree box filters and bioretention cells. Plants, soil and microbes work symbiotically in these situations to alter or reduce the quantity of pollutants collected in storm water and rain water. Some of the nutrients are utilized directly by the plants and soil microbes while others are converted into safe and acceptable levels. Selecting plants that are effective at pollutant reduction is very important to ensure that pollutants are not toxic to the plants.

Air Quality

Equally important to consider is air quality. Plant tolerances of pollutants found in the air vary. Some plants thrive in higher carbon pollutant environments, for example, while others may experience stunted growth. Air pollutants to consider include: carbon monoxide, ground-level ozone, lead, sulfur dioxide, particulate matter, and nitrogen dioxide.

Heat and Cold Tolerance

In addition to soil and water considerations, heat and cold tolerances of plants should be considered. The map of plant hardiness zones in Appendix C identifies areas by the lowest annual minimum temperature. Plants associated with each zone are identified in Appendix D and are generally tolerant of the coldest temperatures in the area. The other consideration is heat tolerance of plants, which in drier and hotter desert regions is equally important and can be detrimental to plant health. This information can be found using the American Horticultural Society Heat Zone Map for the United States. The map identifies the average number of days a specific area experiences day of extreme heat. Also, it is important to consider the reflectivity of surfaces on leaves and bark. Highly reflective surfaces tend to increase the ambient temperature around plants and can cause burn and even death of plants.

When selecting vegetation for low-impact developments it is critical to consider the needs of plants as well as their ability to promote better water, soil and air quality as well as reduce heat caused by development. Native species to the specific area being developed are often better suited to current site conditions; however, impacts created by development also need to be considered to choose the best plant material for each site. Vegetation selection should consider the plants ability to adapt to the proposed site use, water tolerance and needs, changes in soil structure and nutrients currently at the site as well as those brought to a site by storm water runoff. Also, it is important to understand that as a site is developed the minimum and maximum temperatures will change and microclimates will be created. Plants selected should be able to withstand anticipated temperature changes. Furthermore, BMPs require plant selections that can combat the effects of development including storm water runoff, water, soil and air pollutants.

Land Use Examples

The following examples show possible implementations of LID BMPs for three land use types: residential, commercial, and industrial. Figures in the examples are conceptual and as such are not to scale and do not show details for final design.

Residential LID | **Residential Development**

Development Size: 6.61 ac

Imperviousness: 0.51

Runoff Coefficient: 0.17

90^{th} Percentile Storm Depth: 0.55”

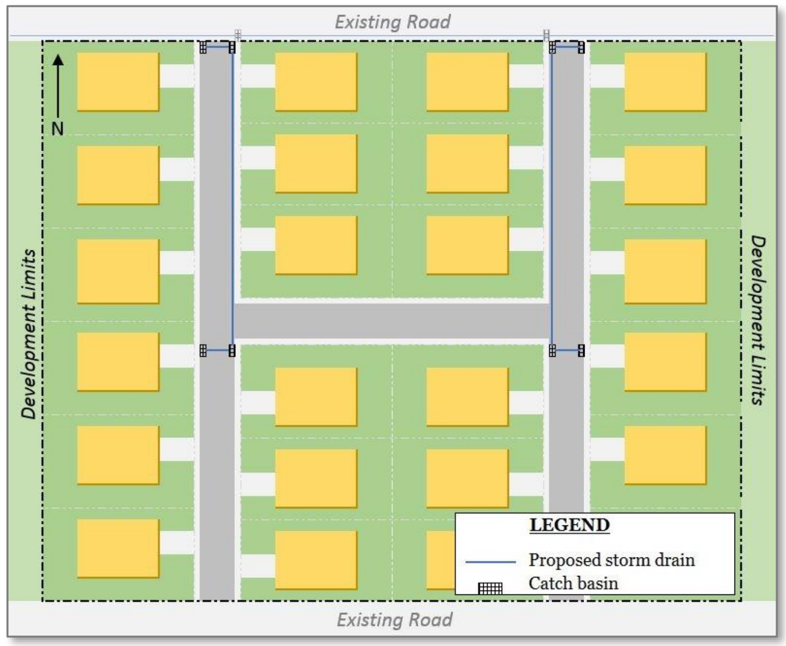


Figure 21: Proposed residential development.

A 6.61-acre residential development (Figure 21) is proposed. The development includes 24 homes, three new thirty-foot wide roads, and sidewalks. The site is graded such that runoff will flow to the north. Catch basins and pipes are proposed as shown to connect to the existing storm drain network that runs east to west on the south side of the existing road north of the development.

With the given plan, the site’s imperviousness is 51%. Using Reese’s method for calculating the runoff coefficient and a 90^{th} percentile storm depth of 0.55”, the volume retention goal of the site is determined to be 5870 cf.

To manage this volume, the design team decided to implement several LID strategies. First, the total impervious surface was reduced by narrowing all roads by 10 feet, which was the minimum roadway width per city guidelines. This resulted in a reduction of impervious area by 0.28 acres, which reduced the site’s total imperviousness to 48%. The volume retention goal was recalculated to be 5474 cf.

To retain the 5474 cf, rain gardens, bioswales, pervious surfaces, and a dry well were strategically placed to capture the volume retention goal to the maximum extent practicable (Figure 22).

Revised LID Design

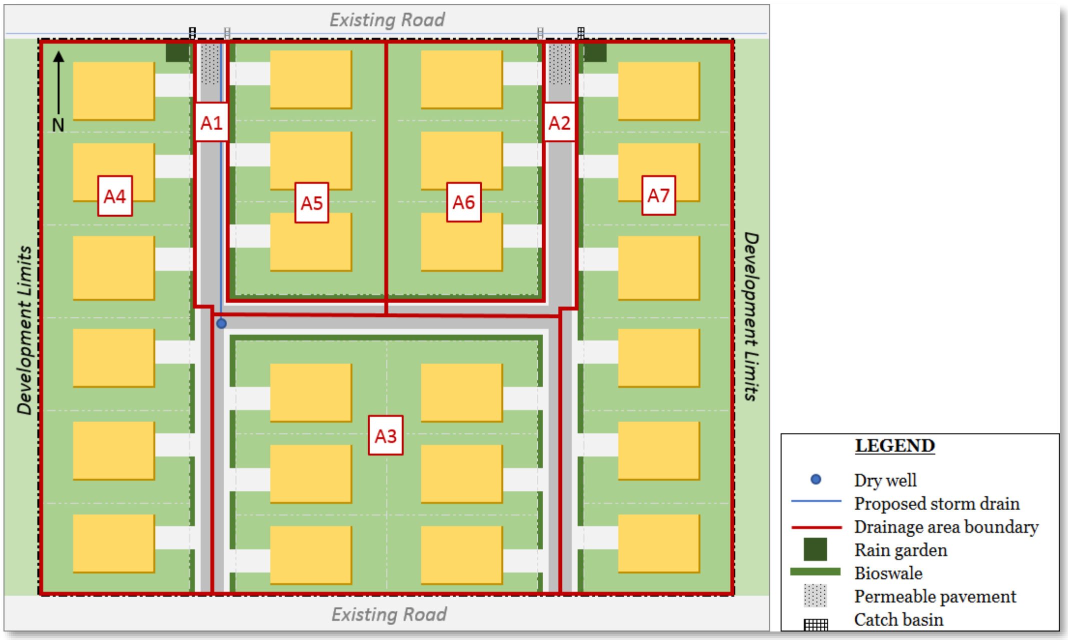


Figure 22: LID approach to residential development.

Contributing Drainage Area	LID BMP Type	Water Quality Volume, WQV (cf)	Runoff Captured (cf)	Percent of WQV Captured	Equivalent Storage Depth	Notes
A1	Permeable Pavement	370	370	100%	6”	
A2	Permeable Pavement	370	370	100%	6”	
A3	Bioswale/Dry Well	1453	937* (bioswale) 565 (dry well)	100%	16” (bioswale)	6’ x 20’ dry well
A4	Bioswale/Rain Garden	1143	238* (bioswale) 906 (rain garden)	100%	6” (bioswale) 24” (rain garden)	
A5	Bioswale	497	527*	100%	18”	
A6	Bioswale	497	527*	100%	18”	
A7	Bioswale/Rain Garden	1143	238* (bioswale) 906 (rain garden)	100%	6” (bioswale) 24” (rain garden)	
	Total	5474	5584	100%		

*33% of water quality volume assumed to infiltrate into bioswales. See the Bioswale fact sheet for further discussion on swale infiltration.

By narrowing the roads and introducing LID BMPs, the design team was able to capture 100% of the project’s volume retention goal. This approach has also reduced the number of catch basins and linear feet of pipe required for the storm drain network (assuming that flood control consideration has also been incorporated into the design).

Development Size: 1.18 ac

Imperviousness: 100%

Runoff Coefficient: 0.89

90th Percentile Storm Depth: 0.55”

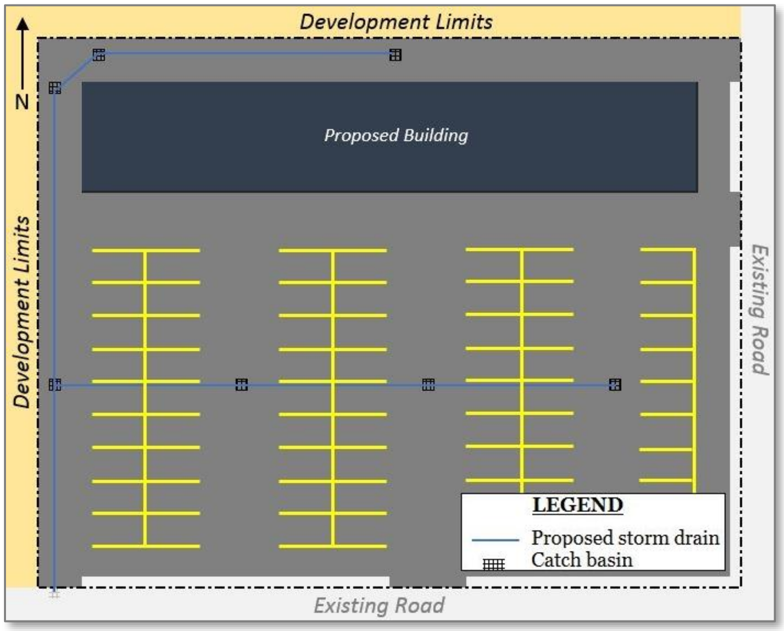


Figure 23: Proposed commercial development.

A 1.18-acre residential development (Figure 23) is proposed. The development includes a 0.21 acre building and 0.97 acres of parking and sidewalk. A storm drain network has been proposed such that flows will be conveyed to a catch basin at the southwest corner of the site.

With the given plan, the site’s imperviousness is 100%. Using Reese’s method for calculating the runoff coefficient and a 90th percentile storm depth of 0.55”, the volume retention goal of the site is determined to be 2088 cf.

To manage this volume, the design team decided to implement three LID features: bioretention areas within the parking lot, and permeable pavement and a bioswale behind the building that will capture runoff from the roof via down drains that were previously designed to discharge into a concrete ditch (Figure 24). Inclusion of these features results in a reduction of impervious area by 0.06 acres, which reduced the site’s total imperviousness to 94%. The volume retention goal was recalculated to be 1959 cf.

The LID features proposed will capture the volume retention goal to the maximum extent practicable.

Revised LID Design

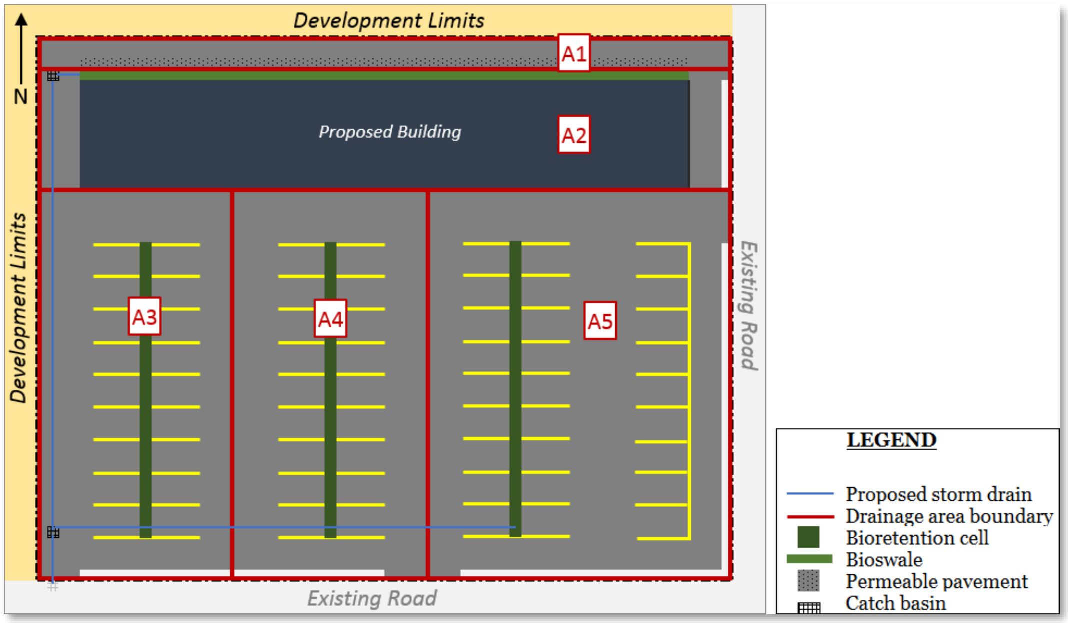


Figure 24: LID approach to commercial development.

Contributing Drainage Area	LID BMP Type	Water Quality Volume, WQV (cf)	Runoff Captured (cf)	Percent of WQV Captured	Equivalent Storage Depth	Notes
A1	Permeable Pavement	119	125	100%	6"	1' width
A2	Bioswale	420	440*	100%	16"	4' width
A3	Bioretention Cell	400	432	100%	12"	4' width
A4	Bioretention Cell	400	432	100%	12"	4' width
A5	Bioretention Cell	620	648	100%	18"	4' width
	Total	1959	2077	100%		

*33% of water quality volume assumed to infiltrate into bioswales. See the Bioswale fact sheet for further discussion on swale infiltration.

By using an LID approach, the design team was able to reduce the volume retention requirement and capture 100% of the project's volume retention goal. Some of the pipe behind the commercial building was replaced with conveyance through the bioswale. Flood control considerations should also be considered for final design.

Development Size: 2.64 ac

Imperviousness: 94%

Runoff Coefficient: 0.83

90^{th} Percentile Storm Depth: 0.55"

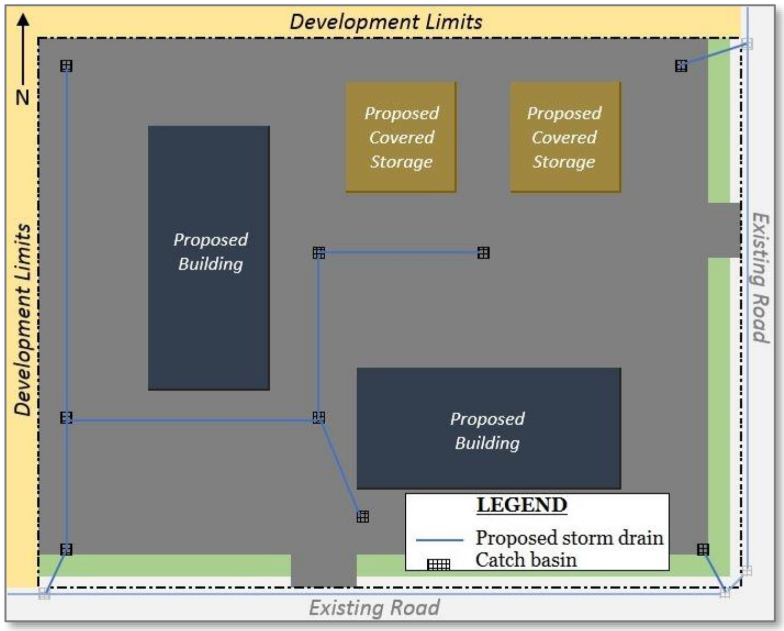


Figure 25: Proposed industrial development.

A 2.64-acre industrial development (Figure 25) is proposed. Two new buildings and two covered storage areas are also proposed. The current site will have 0.32 acres of pervious area adjacent to the new sidewalk. There are three connection points to the storm drain network.

With the given plan, the site's imperviousness is 94%. Using Reese's method for calculating the runoff coefficient and a 90^{th} percentile storm depth of 0.55", the volume retention goal of the site is determined to be 4400 cf.

Upon reevaluating the design of the site and subsurface site conditions, two LID features were determined to be appropriate: two infiltration basins and two infiltration trenches (Figure 26). Altering the grading design created four contributing drainage areas to the basins and trenches which have overflow connections to the existing catch basins. Pervious areas were also increased. Inclusion of these features results in a reduction of impervious area by 0.18 acres, which reduced the site's total imperviousness to 87%. The volume retention goal was recalculated to be 4066 cf.

The LID features proposed will capture the volume retention goal to the maximum extent practicable.

Revised LID Design

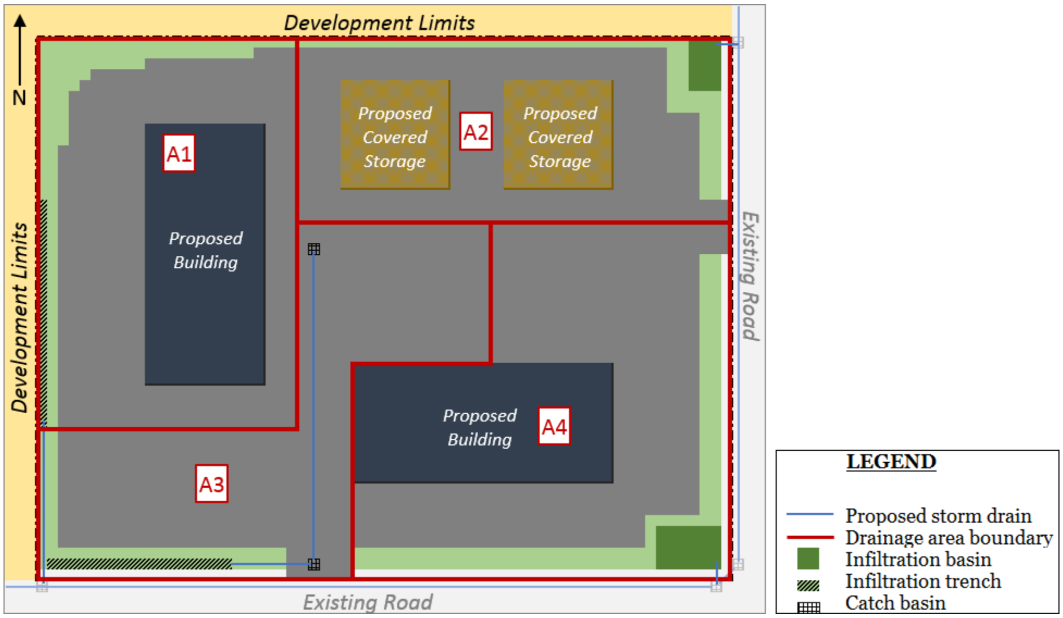


Figure 26: LID approach to industrial development.

Contributing Drainage Area	LID BMP Type	Water Quality Volume, WQV (cf)	Runoff Captured (cf)	Percent of WQV Captured	Equivalent Storage Depth	Notes
A1	Infiltration Trench	1073	1073	100%	18"	4' width
A2	Infiltration Basin	871	871	100%	-	Infiltration rate = 2 in/hr Safety factor = 1.33 Drawdown time = 24 hrs Footprint = 230 sf
A3	Infiltration Trench	881	881	100%	18"	4' width
A5	Infiltration Basin	1242	1242	100%	18"	Infiltration rate = 2 in/hr Safety factor = 1.33 Drawdown time = 24 hrs Footprint = 413 sf
	Total	4066	4066	100%		

The full project volume retention goal was captured by incorporating LID practices. Pipe was able to be removed from the site. Additional water quality measures appropriate for an industrial site such as an oil/water separator are not shown in this example but can be used if necessary. Flood control considerations should be considered for final design.

Appendix A Storm Water Quality Report Template

Storm Water Quality Report – Template

Date: 7/1/2019

Project Name: Garden Valley Condominiums

Project ID: 999999

Design Engineer: John Doe, PE

Is the project within a watershed that is 303(d) listed? Yes

If yes:

Name of receiving water(s): Little Cottonwood Creek-2

Listed Impairment(s): pH; Cadmium, Dissolved; Copper, Dissolved

Does the watershed that has an approved TMDL? Yes

If yes:

Approved TMDL(s): Zinc

I have reviewed the storm water quality design and find this report to be complete, accurate, and current.

Project Manager

[name], Project Manager

Storm Water Coordinator

[name], Permittee's Designate Storm Water Coordinator

[stamp required at advertise]

Maintenance

[name], Permittee's head of Maintenance

Project Information

Type of Project (New Development, Redevelopment): New Development

Area of Land Disturbance (ac): 3.7

Project Impervious Area (ac): 2.9

Project Imperviousness (%): 68

Project Runoff Coefficient, R_V: 0.59

90th Storm Depth (in): 0.64

Project 90th Percentile Volume, V_{goal} (cf): 5110

Groundwater Information

Depth to Groundwater (ft): 17 ft

Historical High Depth to Groundwater if known (ft): 9 ft

Source: Project groundwater monitoring

Soil Information

Infiltration Rate (in/hr): 1.5 in/hr

Source: Project geotechnical report

LID Drainage Areas

(add additional rows as needed)

Contributing Drainage Area	Area (ac)	Impervious Area (ac)	Imperviousness (%)	Runoff Coefficient, R_V	Water Quality Volume, WQV (cf)
CDA 1	0.90	0.50	0.56	0.49	1015
CDA 2	0.75	0.45	0.60	0.53	915
CDA 3	0.80	0.80	1.0	0.89	1654
CDA 4	1.25	0.75	0.60	0.53	1526
				Total WQV (cf)	**5110**

LID BMP Design

(add additional rows as needed)

Contributing Drainage Area	LID BMP Type	Water Quality Volume, WQV (cf)	Runoff Retained (cf)	Percent of Runoff Captured (%)
CDA1	Rain Garden	1015	1023	100
CDA 4	Infiltration Basin	915	920	100
CDA 3	Bioretention Cell	1654	1655	100
CDA 4	Bioretention Cell	1526	1600	100
		Total Volume Retained (cf)	5198	100

Percent of V_{goal} captured by LID BMPs: 100 %

If 100% of V_{goal} is not captured, document and provide narrative of technical infeasibilities and/or alternate compliance measures below:

Describe additional storm water quality measures incorporated into the site:

Appendix B LID BMP Fact Sheets

Rain Garden

BR-1

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	H
Metals	H
Bacteria	H
Oil/Grease	H

H = High
M = Medium
L = Low

Rain gardens are shallow bioretention areas with engineered soil. A variety of plants are used to increase infiltration and nutrient uptake including trees, shrubs, grasses, and other plants suitable for the climate. Rain Gardens are typically designed with various layers of soil, sand, and aggregate. Select any topsoil that is known to thrive within the climate to establish vegetation. They can be topped with a wood or rock mulch, any organic material, or other landscaping features. Performance is increased with high carbon soils. Sand and aggregate layers below the soil layers provide filtration and storage. Rain gardens are usually well-received by the public for their aesthetic qualities.

Slopes leading to the garden bottom are gentle or steep based on site constraints, such as within urban areas. Ponding depths are typically between 1 to 12 inches. Underdrains and impermeable liners are necessary when subsurface concerns exist such as proximity to a structure, poorly infiltrating soils, or groundwater concerns. When a rain garden must be lined, its volume retention function is eliminated, pollutant removal effectiveness is diminished, and it functions primarily as a detention device; however, it still provides treatment through biofiltration. A bypass mechanism either within the rain garden or upstream of the rain garden should be considered for flood events.

Primary Functions	
Bioretention	Yes
Volume Retention	Yes
Filtration	Yes

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters.

Parameter	Min. Value	Max. Value	Notes
Depth to Groundwater	4 ft	No maximum	
Side Slopes	No minimum	3H:1V	
Ponding Depth	No minimum	12 in	
Drawdown Time	12 hours	72 hours	24 to 48 hours preferred
Infiltration Rate	0.5 in/hr	6 in/hr	Field testing required for final design. Infiltration rate should be low enough to allow biofiltration processes to occur. During design, infiltration rate, drawdown time, and the soil matrix depth will be directly related.
Freeboard	No minimum	No maximum	Freeboard per permittee standards. For public safety, consider requiring freeboard and a minimum 6" embankment when ponding depth is greater than 6".

Calculation Methods

Rain garden design is governed by the water quality volume. The general design steps are:

1. Calculate the water quality volume.
2. Determine the geometry of the rain garden.
3. Based on the rain garden geometry and the porosity of the soil layers, determine the ponding depth and soil matrix depth required to hold the water quality volume.
4. Calculate the drawdown time.
5. Calculate the water quality outlet elevation.

Sample Calculations

Refer to Calculation Methods in the Preface to Fact Sheets for discussion on the equations used.

A site has 1500 sf of available open space at the downstream end of a parking lot. The parking lot and an adjacent pervious surface constitute one drainage area that is 0.75 ac in size. The total imperviousness of the drainage area is 0.80. The permittee has developed a maximum drawdown time of 48 hours and uses a safety factor of 1.5 for water quality design.

Given
Contributing drainage area: 0.75 ac
Imperviousness: 0.80
90^{th} percentile storm depth: 0.60"
Soil infiltration rate: 1.75 in/hr

Determine
The footprint and depth of a rain garden that can retain the water quality volume.

Calculations
Runoff coefficient (Reese), R_V
$R_V = (0.91)(0.80) - 0.0204$

$R_V = 0.71$

Water quality volume, WQV
$WQV = R_V dA$
WQV = (0.71)(0.60”) (0.75 ac)(43560 sf/ac) /(12 in/ft)
WQV = 1156 cf

Minimum footprint, A_{min}
$A_{min} = (12)(SF)(WQV)/kt$
A_{min} = (12)(1.50*1156 cf)/(1.75 in/hr)(48 hrs)
A_{min} = 248 sf

The water quality volume will infiltrate into the existing soil in 48 hours if the rain garden bottom is 248 square feet. However, this does not mean that the rain garden bottom is required to be 248 square feet. A larger footprint with a faster drawdown time may be acceptable and reduce the depth required to retain the water quality volume.

A rain garden with a bottom footprint of 720 sf, a 6” ponding depth, and soil layers with the following properties will retain the water quality volume. If a safety factor is desired, it should be accounted for by multiplying the water quality volume by the safety factor.

Rain Garden Effectiveness

Effective rain gardens provide an aesthetically pleasing method for retaining and treating storm water. Visiting rain gardens during rain events will reveal if the garden is draining properly. Rain gardens are performing properly if they are retaining their design volume and treating runoff. Creating and following through on maintenance guidelines are critical to ensuring that a rain garden remains functional.

There are many possible indications that a rain garden has failed or is near failure, such as: ponding beyond the design ponding depth during small storm events, drawdown time exceeds design drawdown time, larger than expected sediment buildup within or upstream of the rain garden, irregular settling of the rain garden bottom creating standing water, sloughing of side slopes, excessive and unmaintained vegetation, lack of vegetation, and no maintenance or no record of maintenance. Although this is not an all-inclusive list, being aware of these items will assist in determining what steps need to be taken to remediate a failing rain garden.

Designer Checklist

	Yes	No
Does groundwater meet the minimum separation requirement?	☐	☐
Is there available right-of-way?	☐	☐
Is the infiltration rate of the existing soils within acceptable rates?	☐	☐
Is contaminated groundwater present?	☐	☐
Is the drainage area to the rain garden less than 5 acres?	☐	☐
Do utility conflicts make installation of the rain garden technically infeasible?	☐	☐
Do geotechnical conditions exist that would compromise the stability of the rain garden or surrounding structures?	☐	☐

Does the soil matrix provide storage for 100% of the water quality volume?	☐	☐
Does an overflow outlet structure exist?	☐	☐

Vegetation Selection

Refer to Vegetation Selection in the Preface to Fact Sheets.

Installation

Excavation

Rain gardens, like other BMPs whose functionality is dependent on infiltration, will fail if proper care is not taken during excavation and construction. Excavators and heavy machinery should not be used within the rain garden area if infiltration is expected to occur through the rain garden bottom. Additional excavation beyond the rain garden's footprint may be required depending on site conditions to provide soil stability or to be able to tie-in to the surrounding grade.

Activities During Construction

Avoid using heavy machinery within the rain garden footprint during construction as doing so will further compact the soils and diminish their infiltrating capabilities. Light machinery and even walking within the rain garden's footprint will also compromise infiltration. Compaction of native soils or backfill below the rain garden subsoils is acceptable if doing so does not prevent infiltration from occurring.

Flows During Construction

Flows during construction should be diverted away from the rain garden to prevent construction site sediment from clogging soils. Scheduling installation of the rain garden shortly after excavation will minimize the impact of unnecessary storm water flows from entering the excavated area. The introduction of unwanted sediment can be prevented by placing fiber rolls or silt fences around the rain garden perimeter during construction.

Additional Guidance

- Require certificates of compliance to verify that construction items meet specification requirements.
- Follow landscaping guidance to ensure that vegetation establishes after installation.

Installation Costs

The following cost items are typically associated with rain garden construction.

-Excavation

-Grading

-Fine grading

-Granular borrow fill

-Landscaping and vegetation

-Top layer

-Engineered soil

-Coarse sand

-Crushed gravel

-Open graded stone

-Geotextile fabric

-Outlet structure

-Observation wells

-Curb and gutter

-Impermeable liner (if needed)

-Underdrain system (if needed)

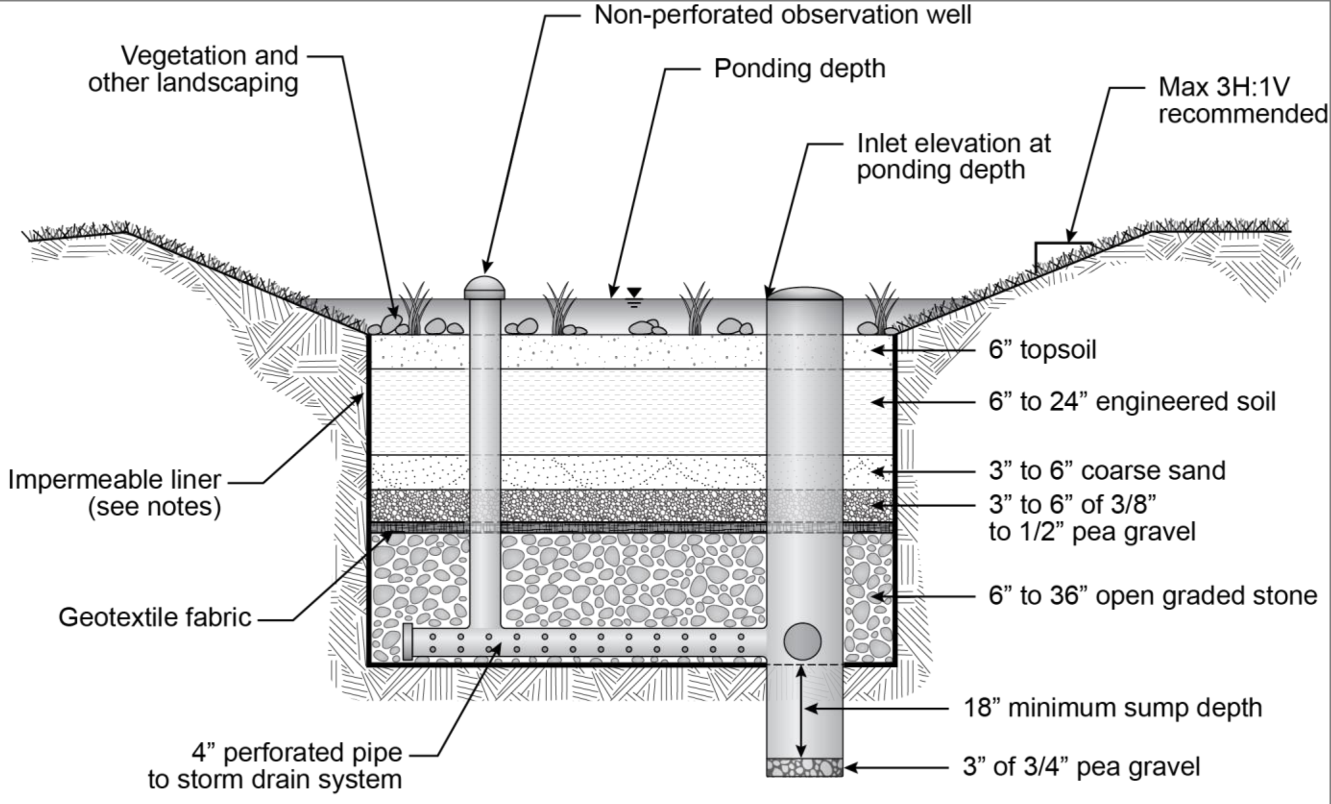
-Irrigation system (if needed)

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of bioretention BMPs.

Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect for adequate vegetative coverage, and impaired or failing vegetation.	Semiannual (Spring, Fall)	Reseed/replant barren spots. Notify the engineer if failing vegetation persists.	L
Inspect side slopes for erosion, rilling, and sloughing.	Semiannual (Spring, Fall)	Regrade side slope if sloughing does not impact slope stability. Notify the engineer if side slope stability has been compromised and is affecting the functionality of the basin.	L
Inspect for trash and debris within basin and at inlet and outlet structures.	Semiannual (Spring, Fall)	Remove and dispose of trash and debris.	L
Inspect for large deposits of sediment on basin bottom indicating soil clogging.	Semiannual (Spring, Fall)	Remove and dispose of built up sediment when buildup causes reduction in size of basin or if buildup results in standing water. Notify the engineer in the case of standing water as it may indicate clogging within the basin’s soil layers.	L
Inspect for standing water within rain garden or within observation well.	Semiannual (Spring, Fall) or as needed	Notify the engineer for further inspection.	M
Inspect for failure of additional features such as underdrains or irrigation systems.	Semiannual (Spring, Fall) or as needed	Repair as needed.	M



Notes:

- *Impermeable liner around all sides and bottom of rain garden if groundwater concerns exist*
- *Dimensions shown may vary based on site conditions*

Rain Garden

Not to scale

UTAH DEPARTMENT *of* ENVIRONMENTAL QUALITY
WATER QUALITY

Bioretention Cell *BR-2*

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	H
Metals	H
Bacteria	H
Oil/Grease	H

H = High
M = Medium
L = Low

Bioretention cells are shallow bioretention areas with engineered soil. They typically differ from rain gardens by having a delineation such as a curb, wall, or other distinct boundary. Similar to a rain garden, a variety of plants are used to increase infiltration and nutrient uptake including trees, shrubs, grasses, and other plants suitable for the climate. They are typically designed with various layers of soil, sand, and aggregate. Select any topsoil that is known to thrive within the climate to establish vegetation. They can be topped with a wood or rock mulch, any organic material, or other landscaping features. Performance is increased with high carbon soils. Sand and aggregate layers below the soil layers provide filtration and storage.

Primary Functions	
Bioretention	Yes
Volume Retention	Yes
Filtration	Yes

Slopes leading to the garden bottom are gentle or steep based on site constraints, such as within urban areas. Ponding depths are usually between 1 to 12 inches. In areas with high foot traffic, it may be necessary to provide a safety bench of soil within the cell and a minimum side slope leading to the cell bottom. Underdrains and impermeable liners are necessary when subsurface concerns exist such as proximity to a structure, poorly infiltrating soils, or groundwater concerns. When a bioretention cell must be lined, its volume retention function is eliminated, its pollutant removal effectiveness is diminished, and it functions primarily as a detention device; however, it still provides treatment through biofiltration. A bypass mechanism either within the bioretention cell or upstream of the cell should be considered for flood events.

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters.

Parameter	Min. Value	Max. Value	Notes
Depth to Groundwater	4 ft	No maximum	
Ponding Depth	No minimum	12 in	
Drawdown Time	12 hours	72 hours	24 to 48 hours preferred
Infiltration Rate	0.5 in/hr	6 in/hr	Field testing required for final design. Infiltration rate should be low enough to allow biofiltration processes to occur. During design, infiltration rate, drawdown time, and the soil matrix depth will be directly related.
Freeboard	No minimum	No maximum	Freeboard per permittee standards. For public safety, consider requiring freeboard and a minimum 6" embankment when ponding depth is greater than 6".

Calculation Methods

Bioretention cell design is governed by the water quality volume. The general design steps are:

1. Calculate the water quality volume.
2. Determine the geometry of the bioretention cell.
3. Based on the bioretention cell geometry and the porosity of the soil layers, determine the ponding depth and soil matrix depth required to hold the water quality volume.
4. Calculate the drawdown time.
5. Calculate the water quality outlet elevation.

Sample Calculations

A drainage area within a proposed roadway will be one-third of an acre with 90% imperviousness. It is proposed that three bioretention cells be placed within the drainage area creating three sub-drainage areas. Each sub-drainage area has the same imperviousness.

<u>Given</u>
Contributing drainage area: 0.11 ac
Imperviousness: 0.90
Storm depth: 0.50 inches
Soil infiltration rate: 1.60 in/hr

<u>Determine</u>
The footprint and depth of the bioretention cells that can retain the water quality volume.

<u>Calculations</u>
Runoff coefficient (Reese), R_V
$R_V = (0.91)(0.90) - 0.0204$
$R_V = 0.80$

Water quality volume, WQV
WQV = (0.80)(0.50”) (0.11 ac)(43560 sf/ac)/(12 in/ft)
WQV = 159 cf

Minimum footprint, A_{min}
A_{min} = (12)(1.50)(159 cf)/(1.60 in/hr)(48 hrs)
A_{min} = 38 sf

The water quality volume will infiltrate into the existing soil in 48 hours if the footprint area of all bioretention cells is 38 square feet. However, this does not mean that the bioretention cell footprint is required to be 38 square feet. A larger footprint with a faster drawdown time is acceptable and will reduce the depth required to retain the water quality volume.

A bioretention cell with a bottom footprint of 200 sf and soil layers with the following properties will retain the water quality volume. If a safety factor is desired, it should be accounted for by multiplying the water quality volume by the safety factor.

Layer	Thickness, in	Porosity	Storage Volume, cf
Ponding	3	1.0	50
Top Soil	6	0.25	25
Engineered Soil	8	0.25	33.3
Coarse Sand	3	0.35	17.5
Pea Gravel	3	0.25	17.5
Aggregate Storage	4	0.4	26.7
Total	24 (soil layers)	0.37 (soil layers weighted)	165 (includes ponding)

Bioretention Cell Effectiveness

Effective bioretention cells provide an aesthetically pleasing method for retaining and treating storm water. Inspecting bioretention cells during rain events will reveal if the garden is draining properly. Bioretention cells are performing properly if they are retaining their design volume and treating runoff. Creating and following through on maintenance guidelines are critical to ensuring that a bioretention cell remains functional.

There are many possible indications that a bioretention cell has failed or is near failure, such as: ponding beyond the design ponding depth during small storm events, drawdown time exceeds design drawdown time, larger than expected sediment buildup within or upstream of the rain garden, excessive and unmaintained vegetation, lack of vegetation, obstructions at the inlet and outlet locations, and no maintenance or no record of maintenance. Although this is not an all-inclusive list, being aware of these items will assist in determining what steps need to be taken to remediate a failing bioretention cell.

Designer Checklist

	Yes	No
Does groundwater meet the minimum separation requirement?	☐	☐

Is there available right-of-way for the bioretention cell?	☐	☐
Is the infiltration rate of the existing soils within acceptable rates?	☐	☐
Is contaminated groundwater present?	☐	☐
Is the drainage area less than 5 acres?	☐	☐
Are there utility conflicts with the bioretention cell that can't be resolved?	☐	☐
Do geotechnical conditions exist that compromise the stability of nearby structures?	☐	☐
Does the soil matrix provide storage for 100% of the water quality volume?	☐	☐
Does an overflow outlet structure exist?	☐	☐

Vegetation Selection

Refer to Vegetation Selection in the Preface to Fact Sheets.

Installation

Excavation

Bioretention cells, like other BMPs whose functionality is dependent on infiltration, will fail if proper care is not taken during excavation and construction. Excavators and heavy machinery should not be used within the excavated area if infiltration is expected to occur through the bioretention cell bottom. Additional excavation beyond the footprint may be required depending on site conditions to provide soil stability or to be able to tie-in to the surrounding grade.

Activities During Construction

Avoid using heavy machinery within the bioretention cell footprint during construction as doing so will further compact the soils and diminish their infiltrating capabilities. Light machinery and even walking within the bioretention cell's footprint will also compromise infiltration. Compaction of native soils or backfill below the bioretention cell subsoils is acceptable if doing so does not prevent infiltration from occurring.

Flows During Construction

Flows during construction should be diverted away from the bioretention cell to prevent construction site sediment from clogging soils. Scheduling installation of the bioretention cell shortly after excavation will minimize the impact of unnecessary storm water flows from entering the excavated area. The introduction of unwanted sediment can be prevented by placing fiber rolls or silt fences around the bioretention cell perimeter during construction.

Additional Guidance

- Require certificates of compliance to verify that construction items meet specification requirements.
- Follow landscaping guidance to ensure that vegetation establishes after installation.

Installation Costs

The following cost items are typically associated with bioretention cell construction.

-Excavation

-Landscaping and vegetation

-Top layer

-Engineered soil

-Coarse sand

-Crushed gravel

-Open graded stone

-Geotextile fabric

-Outlet structure

-Observation wells

-Curb and gutter

-Impermeable liner (if needed)

-Underdrain system (if needed)

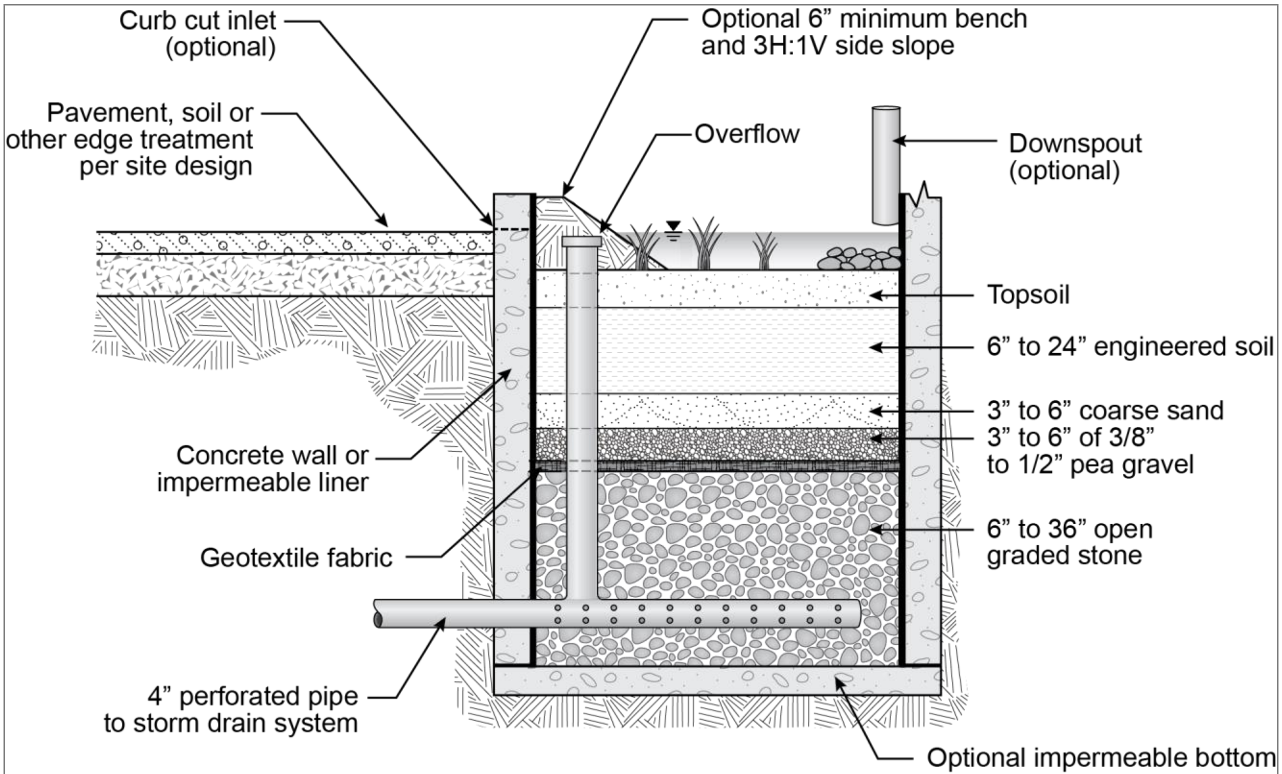
-Irrigation system (if needed)

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of bioretention BMPs.

Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect for adequate vegetative coverage, and impaired or failing vegetation.	Semiannual (Spring, Fall)	Reseed/replant barren spots. Notify the engineer if failing vegetation persists.	L
Inspect for trash and debris within basin and at inlet and outlet structures.	Semiannual (Spring, Fall)	Remove and dispose of trash and debris.	L
Inspect for large deposits of sediment on bottom indicating soil clogging.	Semiannual (Spring, Fall)	Remove and dispose of built up sediment when buildup causes reduction in size of basin or if buildup results in standing water. Notify the engineer in the case of standing water as it may indicate clogging within the basin's soil layers.	L
Inspect for standing water within bioretention cell or within observation well.	Semiannual (Spring, Fall) or as needed	Notify the engineer for further inspection.	M
Inspect for failure of additional features such as underdrains or irrigation systems.	Semiannual (Spring, Fall) or as needed	Repair as needed.	M



Notes:

- *Overflow elevation must be below elevation of inlet (curb cut, downspout, or other per site design)*
- *Dimensions shown may vary based on site conditions*

Bioretention Cells

Not to scale

Bioswale

BR-3

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	M
Nutrients	L
Metals	M
Bacteria	L
Oil/Grease	H

H = High
M = Medium
L = Low

Bioswales are vegetated open channels designed to convey and treat storm water runoff. They are appropriate when it is desirable to convey flows away from structures or as an alternate conveyance method to pipes, concrete channels, or curbed gutters. Bioswales reduce peak flow rates, reduce flow velocities, increase the time of concentration, filter storm water pollutants, and can also reduce runoff volume through infiltration.

The primary functions of bioswales are bioretention and treatment through biofiltration. Conveying runoff through bioswales allows the runoff to be filtered through two processes: bioretention through the soil matrix and biofiltration through the above ground vegetation.

Although volume retention may be accomplished within a subsoil matrix of engineered soil and gravel layers, retention is not its primary function. However, retention volumes may be determined by designing ponding areas within the swale or creating check dams. There is research to support the quantification of infiltration when runoff is simply conveyed through the swale (no ponding) but design parameters vary widely. Monitoring bioswales for volume reduction is the most reliable source for future estimates of expected reduction.

Primary Functions	
Bioretention	Yes
Volume Retention	Some
Filtration	Yes

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters.

Parameter	Min. Value	Max. Value	Notes
Length	Based on hydraulic residence time	No maximum	
Longitudinal Slope	0.50%	5%	Underdrain recommended below minimum slope
Bottom Width	No minimum	No maximum	
Side Slope	No minimum	3H:1V	Per permittee requirements
Flow Velocity	No minimum	1.0 ft/s	Maximum permissible shear stress may also dictate maximum flow velocity
Flow Depth	No minimum	2/3 vegetation height	Flow depths greater than vegetation height will bypass the biofiltration processes
Freeboard	No minimum	No maximum	Per permittee requirements
Vegetation Coverage	≥ 70%		Biofiltration is significantly reduced when vegetation coverage is less than 70%
Hydraulic Residence Time	5 min	No maximum	

Calculation Methods

Bioswale design is governed by the water quality flow. The general design steps are:

1. Calculate the water quality flow.
2. Determine the geometry of the bioswale's cross-section.
3. Determine the flow depth.
4. Determine volume retention within bioswale, if any.
5. Check flow velocity and hydraulic residence time.

Sample Calculations

During the planning phase of a city roadway project it has been decided to remove curbs and instead allow one acre of runoff to sheet flow into a 500 ft bioswale. There are 15 feet of available right-of-way between the edge of pavement and the project limits. A 4-foot sidewalk is also proposed to be within the right-of-way. The city has a requirement that there be no slopes greater than 6H:1V within five feet of the edge of pavement. The city's storm water requirements state that the 2-yr, 6-hr intensity must be used in determining the water quality flow rate. Per city standards, 6 inches of freeboard will be required above the water quality flow depth.

<u>Given</u>
Contributing drainage area: 1.0 ac
Imperviousness: 0.85
90^{th} percentile storm depth: 0.60 inches
2-yr, 6-hr storm intensity: 0.16 in/hr

Design Goals
Determine an acceptable swale bottom width and flow depth. Design a soil matrix and determine the volume of runoff that is expected to infiltrate into the bioswale.

Calculations
Runoff coefficient (Reese), R_V
$R_V = (0.91)(0.85) - 0.371$
$R_V = 0.75$

Water quality flow, WQF
$WQF = R_V iA$
$WQF = (0.75)(0.16 \text{ in/hr})(1.0 \text{ ac})$
$WQF = 0.12 \text{ cfs}$

The project team has decided that a 2-foot bottom width will be used for the bioswale. Per city standards, 6 inches of freeboard will be required above the water quality flow depth. Other design information for the bioswale includes:
Longitudinal slope: 2.0%
Side slopes: 3H:1V

Determine the flow depth during the design storm event by setting Manning's equation equal to the WQF and solving the equation for the flow depth, y_d. This calculation is made easier using a goal seek function within a spreadsheet.
$y_d = 2"$

The city requires that flows remain below 1 ft/s to prevent scouring of the bioswale bottom. With the flow depth known, the continuity equation can be used to determine the flow velocity. The cross-sectional area is calculated to be 0.42 sf.
$v = Q/A$
$v = 0.12 \text{ cfs} / 0.42 \text{ sf}$
$v = 0.28 \text{ ft/s}$

The city also requires a 5-minute minimum hydraulic residence time to achieve the maximum desired biofiltration. Using the velocity, a minimum swale length can be determined.
$L_{min} = (0.28 \text{ ft/s})(300 \text{ s})$
$L_{min} = 84 \text{ ft}$
Any portion of the runoff that enters the swale within 84 ft of the downstream end of the swale will not receive the optimal treatment.

With 6 inches of freeboard and a side slope of 3H:1V, the top width of the bioswale is 6.00 ft. With 15 feet of available right-of-way, 6 of which are available for the swale, at the planning level there is adequate space for the bioswale. If needed, the swale's top width could be narrowed by decreasing the bottom width, which would also result in a deeper flow depth.

Water quality volume, WQV
$WQV = (0.75)(0.60")(1.0 \text{ ac})(43560 \text{ sf/ac})/12 \text{ in/ft})$
$WQV = 1640 \text{ cf}$

The swale will also include 6" high check dams to increase the volume retention. With a longitudinal slope of 2%, a 6" check dam will create a pool that is 25 ft long before overtopping the check dam. The volume retained behind the check dam is calculated with the bottom width, the check dam height, and the length of the check dam pool.

$V_{check\ dam}$ = (2 ft)(25 ft)(0.5 ft) / 2
$V_{check\ dam}$ = 12.50 cf

If the check dams are spaced every 50 feet, 10 check dams are possible, and the total volume retained by the check dams will be 125 cf.

Additional volume retention can be achieved in any ponding areas that are designed into the swale.

The bioswale's primary function is treatment via biofiltration as runoff interacts with the vegetation within the swale. Although methodologies have been developed to determine volume retention within a bioswale, the current body of research varies widely and the permittee is encouraged to exercise engineering judgment.

A conservative design for the soil matrix below the swale will allow for the maximum possible percentage of the water quality volume to be captured; however, for flood control purposes, zero infiltration is assumed. Accounting for the ten check dams, the soil matrix below will provide storage for the remaining portion of the water quality volume (1515 cf). Whether the full remaining volume is captured can be determined by monitoring the swale for volume retention.

Layer	Thickness, in	Porosity	Storage Volume, cf
Engineered Soil	12	0.25	250
Coarse Sand	3	0.35	87.5
Pea Gravel	3	0.25	62.5
Aggregate Storage	34	0.4	1133.3
Total	52 (soil layers)	0.35 (soil layers weighted)	1533 (includes ponding)

Bioswale Effectiveness

Bioswales are effective when they can accomplish their design goals of conveying flows to a downstream receiving structure, BMP, or other receiving area. Flows through the swale should be relatively steady and uniform during a rain event unless retention areas and check dams are part of the swale design. Established vegetation with adequate coverage is an indication of a healthy bioswale along with minimal sediment and lack of invasive vegetation.

Designer Checklist

	Yes	No
Can the longitudinal slope be greater than the minimum?	☐	☐
If longitudinal slope is less than minimum, can underdrain be installed?	☐	☐
If an underdrain is needed, is sufficient hydraulic head available for proper drainage?	☐	☐
Do flows result in a shear stress below the maximum permissible for selected vegetation?	☐	☐
Will the bioswale and its soil matrix create utility conflicts that can't be resolved?	☐	☐

Will the bioswale provide conveyance for larger storm events?	☐	☐
Is the bioswale providing pretreatment for a downstream BMP?	☐	☐
Is the bioswale connecting directly to the storm drain network?	☐	☐

Vegetation Selection

Refer to Vegetation Selection in the Preface to Fact Sheets.

Installation

Excavation

Bioswale construction is a relatively straightforward process of excavating the swale's subsurface trench prior to backfilling with any underdrain system, open graded stone, engineered soil, and geotextile fabric. Additional excavation beyond the swale's footprint may be required depending on site conditions to provide soil stability or to be able to tie-in to the surrounding grade.

Activities During Construction

Crews should avoid stepping within the trench except when necessary as doing so will compact the native soil that is expected to infiltrate runoff.

Flows During Construction

Flows during construction should be diverted away from the bioswale to prevent construction site sediment from clogging soils and to prevent erosion of the swale bed. Scheduling installation of the bioswale shortly after excavation will minimize the impact of unnecessary storm water flows from entering the excavated area. The introduction of unwanted sediment can be prevented by placing fiber rolls or silt fences around the bioswale perimeter during construction. Creating the upstream inlet or connection should be the last construction activity before flows are permitted to be conveyed as designed through the bioswale.

Additional Guidance

- Require certificates of compliance to verify that construction items meet specification requirements.
- Follow landscaping guidance to ensure that vegetation establishes after installation.

Installation Costs

The following cost items are typically associated with bioswale construction.

-Excavation

-Grading

-Fine grading

-Granular borrow fill

-Landscaping and vegetation

-Top layer

-Engineered soil

-Open graded stone

-Geotextile fabric

-Impermeable liner

-Outlet structure

-Observation wells

-Underdrain system (if needed)

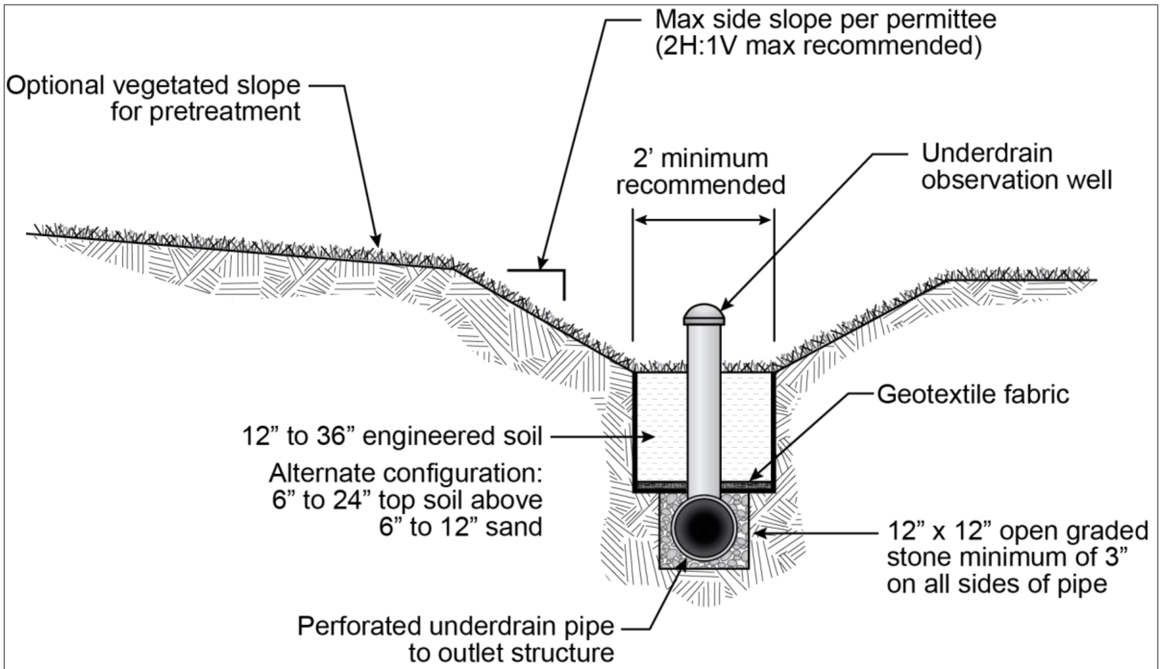
-Outlet protection such as riprap or other (if needed)

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of bioretention BMPs.

Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect for adequate vegetative coverage, and impaired or failing vegetation.	Semiannual (Spring, Fall)	Reseed/replant barren areas. Notify engineer if issue persists.	L
Inspect side slopes for erosion, rilling, and sloughing.	Semiannual (Spring, Fall)	Regrade side slope if slope stability is not affected by sloughing. Notify engineer if stability is affecting basin functionality.	L
Inspect for standing water within bioswale or within observation well.	Semiannual (Spring, Fall)	Notify engineer for further inspection.	M
Inspect for trash and debris at inlet and outlet structures.	Prior to mowing, at least semiannually	Remove trash and debris.	L
Inspect vegetation height.	As needed	Mow swale as needed.	L



Notes:

- *Engineered soil will improve filtration*
- *Underdrain recommended for longitudinal slopes < 1%*
- *Dimensions shown may vary based on site conditions*

Bioswales

Not to scale

UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
WATER QUALITY

Vegetated Strip *BR-4*

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	M
Metals	M
Bacteria	H
Oil/Grease	H

H = High
M = Medium
L = Low

Vegetated strips are designed to receive and treat sheet flow from adjacent surfaces. This is accomplished by slowing runoff velocity to allow for pollutants and sediments to settle and by filtering out pollutants before entering the storm sewer system. Vegetated strips are best utilized for storm water treatment from roads, parking lots, and other impervious surfaces.

The primary functions of vegetated strips are bioretention and treatment. Bioretention within a vegetated strip occurs as runoff enters the soil and pollutants are removed through physical, chemical, and biological processes. Similar biofiltration processes occur to provide treatment when runoff passes through the strip's vegetation.

Primary Functions	
Bioretention	Yes
Volume Retention	No
Filtration	Yes

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters.

Parameter	Min. Value	Max. Value	Notes
Length	15 ft	No maximum	
Longitudinal Slope	No minimum	4H:1V	Per permittee requirements
Flow Velocity	No minimum	1.0 ft/s	Maximum permissible shear stress may also dictate maximum flow velocity
Flow Depth	No minimum	2/3 vegetation height	Flow depths greater than vegetation height will bypass the biofiltration processes
Freeboard	No minimum	No maximum	Per permittee requirements
Vegetation Coverage	≥ 70%		Biofiltration is significantly reduced when vegetation coverage is less than 70%

Calculation Methods

Vegetated strip design is governed by the water quality flow. The general design steps are:

1. Calculate the water quality flow.
2. Determine the flow depth.
3. Check flow velocity.

Sample Calculations

A roadway project is proposing to widen a road that is near a canal. Due to high groundwater and poor soils, retention on-site is not feasible. Treatment is still an option, however, and the design team has decided to establish vegetation within the twenty feet between the edge of pavement and the canal. The city's storm water requirements state that the 2-yr, 2-hr intensity must be used in determining the water quality flow rate.

Given
Contributing drainage area: 0.25 ac
Imperviousness: 1.00
2-yr, 2-hr storm intensity: 0.318 in/hr

Design Goals
Determine that the flow depth will be less than 1 inch.

Calculations
Runoff coefficient (Reese), R_V
$R_V = (0.91)(1.00) – 0.0204$
$R_V = 0.89$

Water Quality Flow, WQF
$WQF = R_V iA$
$WQF = (0.89)(0.318 \text{ in/hr})(0.25 \text{ ac})$
$WQF = 0.071 \text{ cfs}$

There is available right-of-way for a 300-foot long strip that is 20 feet wide. The embankment side slope is 10H:1V which corresponds to a 10% longitudinal slope for the vegetated strip.

Calculation of the flow depth is typically done using Manning's equation setting the equation equal to the water quality flow and solving for the flow depth.

$y_d = [(nQ)/1.49LS^{0.5}]^{0.6}$

$y_d = [(0.2)(0.071 \text{ cfs}) / (1.49)(300 \text{ ft})(0.02)^{0.5}]^{0.6}$

$y_d = 0.04"$

The city requires that flows remain below 1 ft/s to prevent scouring of the strip bottom. With the flow depth known, the cross-sectional area is calculated to be 0.37 sf.

$v = Q/A$

$v = 0.071 \text{ cfs} / 1.10 \text{ sf}$

$v = 0.06 \text{ ft/s}$

Vegetated strips provide treatment through biofiltration but determining volume retention is best accomplished through monitoring.

Vegetated Strip Effectiveness

Vegetated strips are effective when they can accomplish their design goals of conveying sheet flow to the receiving area. Flows through the vegetated strip should be relatively steady and uniform during a rain event and should not create rilling or other visible signs of erosion. Established vegetation with adequate coverage is an indication of a healthy vegetated strip along with minimal sediment and lack of invasive vegetation.

Designer Checklist

	Yes	No
Is the vegetated strip length greater than or equal to the minimum required length?	☐	☐
Do flows result in a shear stress below the maximum permissible for selected vegetation?	☐	☐
Is the vegetated strip providing pretreatment for a downstream BMP?	☐	☐
Is the slope in the direction of flow less than or equal to the permittee's standards?	☐	☐

Vegetation Selection

Refer to Vegetation Selection in the Preface to Fact Sheets.

Installation

Vegetated strips can be installed as part of normal construction activities. An appropriate grass such as turf sod should be installed per specifications. If additional vegetation such as shrubs or bushes will be used within the strip, follow landscaping guidance to ensure that vegetation establishes after installation. To maximize infiltration performance, minimize use of heavy machinery.

Additional Guidance

- Require certificates of compliance to verify that construction items meet specification requirements.

Installation Costs

The following cost items are typically associated with bioswale construction.

-Grading

-Landscaping and vegetation

-Topsoil

-Engineered soil

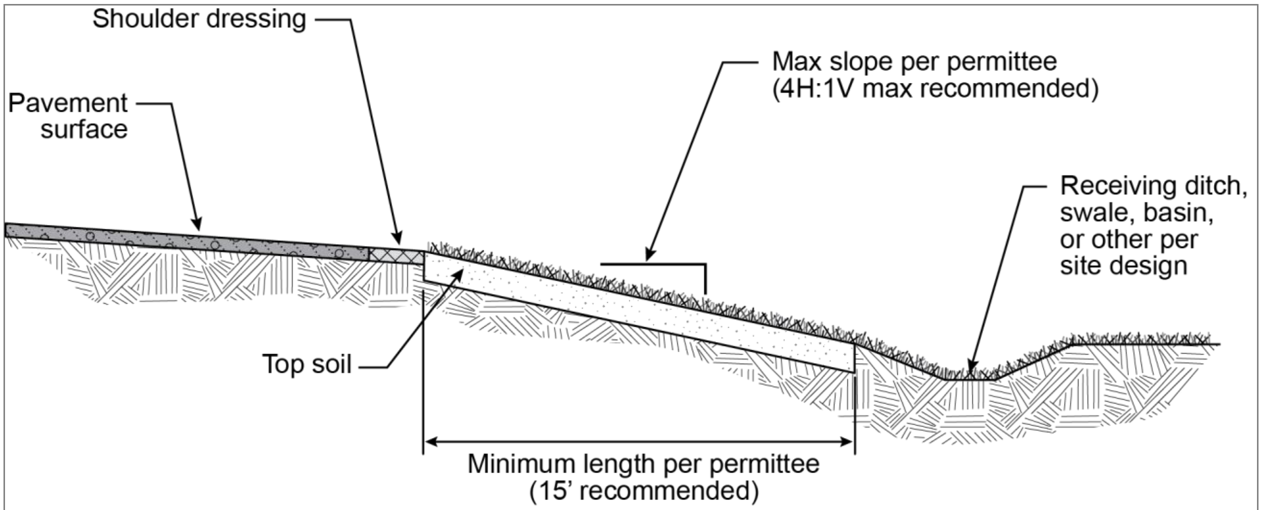
-Shoulder dressing upstream of vegetated strip

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of bioretention BMPs.

Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect upstream end of vegetated strip for sediment buildup that may be impeding sheet flow.	Semiannual	Remove and dispose of sediment buildup.	L
Inspect grass length.	As needed	Mow strip as needed.	L
Inspect for erosion, rilling, and sloughing.	Semiannual	Regrade side slope if slope stability is not affected by sloughing. Notify engineer if stability is affecting basin functionality.	L
Inspect for adequate vegetative coverage, and impaired or failing vegetation.	Semiannual (Spring, Fall)	Reseed/replant barren areas. Notify engineer if issue persists.	L



Notes:

- *Dimensions shown may vary based on site conditions*

Vegetated Strips

Not to scale

Tree Box Filter

BR-5

Source: Montgomery County, Maryland Department of Environmental Protection

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	M
Metals	M
Bacteria	H
Oil/Grease	H

H = High
M = Medium
L = Low

Tree box filters are bioretention systems that are appropriate in urban drainage areas where space is limited. An underground concrete vault contains the soil matrix that provides bioretention and has a grated top where vegetation grows. Tree box filters are typically designed as flow-through devices, meaning that they do not retain storm water but rather allow flows to pass through them. However, a bottomless concrete vault will function as a bioretention system that provides infiltration into the native soils. Manufacturers have developed proprietary designs for tree box filters but they may also be designed.

The primary functions of tree box filters are bioretention and treatment. Runoff from the contributing drainage area enters the tree box through an inlet where bioretention occurs. Storm water is treated by the physical, chemical, and biological processes that occur within the mulch, soil matrix, and plant roots.

Primary Functions	
Bioretention	Yes
Volume Retention	No
Filtration	Yes

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters. Tree box filters may be proprietary devices; follow manufacturer specifications to determine design criteria on a case-by-case basis.

Parameter	Min. Value	Max. Value	Notes
Depth to Groundwater	4 ft	No maximum	May be less than 4 feet if tree box filter has impermeable bottom.
Ponding Depth	No minimum	12 in	
Drawdown Time	12 hours	72 hours	24 to 48 hours preferred
Infiltration Rate	0.5 in/hr	6 in/hr	Field testing required for final design. Infiltration rate should be low enough to allow biofiltration processes to occur. During design, infiltration rate, drawdown time, and the soil matrix depth will be directly related.

Calculation Methods

Tree box filters are typically sized based on their water quality flow but may be sized for their water quality volume when being designed for retention. Both design approaches are dependent on the contributing drainage area and imperviousness. A larger contributing drainage area will require a larger tree box filter.

Tree Box Filter Effectiveness

Tree box filters are effective when they maintain their bioretention and biofiltration capabilities. Proper inspection and maintenance of tree box filters will ensure that the chemical and biological processes that treat runoff perform optimally. Qualified inspection crews are necessary to determine if soils and vegetation are healthy.

The tree box must be able to function hydraulically. Flows must be able to pass through the filter without backing up or maintenance will be required.

Designer Checklist

	Yes	No
Is there adequate space for a tree box filter?	☐	☐
Is there sufficient hydraulic head for tree box filter to connect to storm drain network?	☐	☐
If retention is desired, will the infiltration rate permit a reasonable drawdown time?	☐	☐
If retention is desired, is depth to groundwater from the filter bottom greater than 4 feet?	☐	☐

Vegetation Selection

Refer to Vegetation Selection in the Preface to Fact Sheets or manufacturer's specifications.

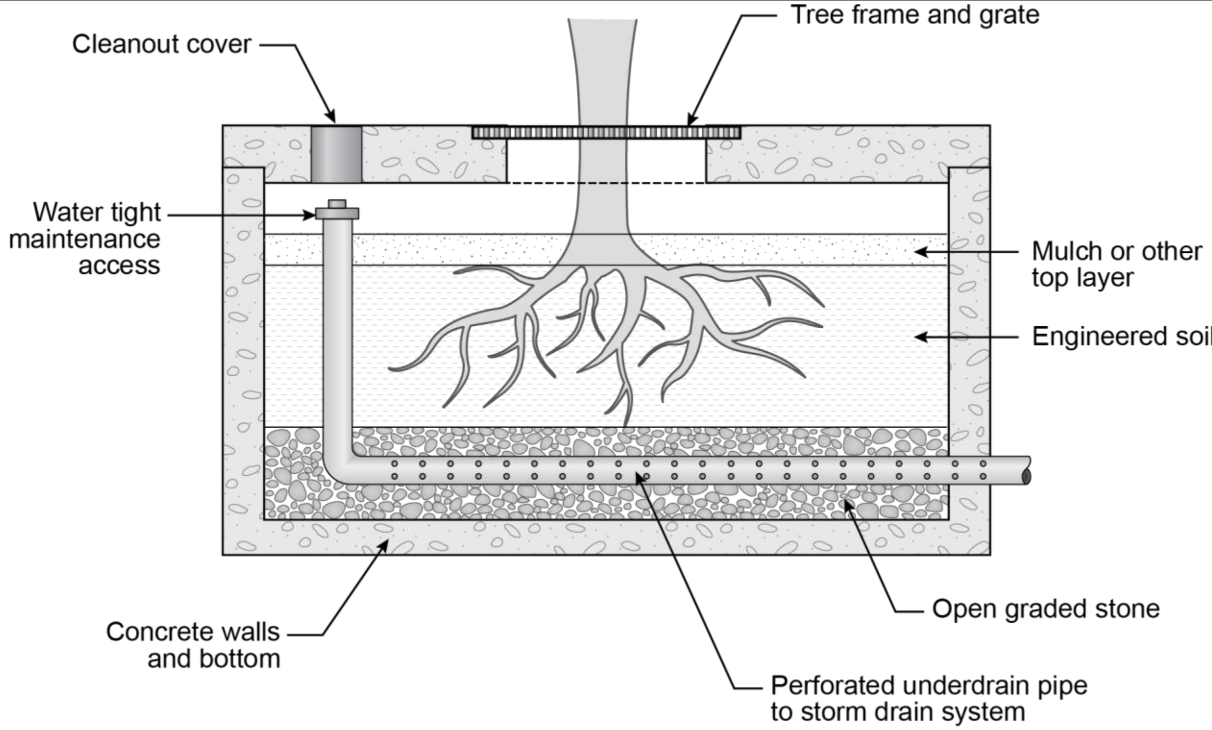
Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of bioretention BMPs.

Maintenance Activities

Proper maintenance of tree box filters will be per the manufacturer's specifications, but it typically includes the following:

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect for trash and debris within tree box filter and at inlet and outlet structures.	Semiannual	Remove trash, debris and sediment.	L
Inspect performance.	Semiannual	Replenish media filter layer with new mulch.	M
Inspect for invasive species.	Semiannual	Prune and weed filter box.	M



Notes:

- *Dimensions shown may vary based on site conditions*

Tree Box Filters

Not to scale

Green Roof

BR-6

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	L
Metals	H
Bacteria	H
Oil/Grease	-

H = High
M = Medium
L = Low

A green roof is a vegetated system that is designed to retain and treat rooftop runoff. The primary functions of green roofs are bioretention, volume retention, and filtration. Green roofs capture storm water within the pore space of the soil and vegetation and the moisture is then released through evapotranspiration.

Green roofs can be classified as either extensive or intensive systems. Extensive systems are those in which the soil media is up to 6 inches in depth and support smaller grasses and other vegetative species that don't have deep root systems. Intensive systems are those that support root systems greater than 6 inches such as those from trees and bushes.

The design of green roofs should be done with the coordination of qualified landscaping, structural, and maintenance teams. Vegetation selection and the proper maintenance of vegetation are critical items in the overall performance and functionality of the green roof. The integrity of the roof structure must also be accounted for as large volumes of plants, soils, water, and the weight of the green roof structure will create additional loads on the building.

Primary Functions	
Bioretention	Yes
Volume Retention	Yes
Filtration	Yes

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters.

Parameter	Extensive	Intensive	Notes
Drawdown Time	12 hours	12 hours	
Growth Media Depth	< 6 in	6+ in	
Vegetation	Low growing, low water-use vegetation such as Sedum, herbs, grasses, and perennials	More complex gardens including the species listed for extensive green roofs, but also incorporating trees and shrubs.	
Load	12-54 lb/sf	72+ lb/sf	
Roof Slope	5:1 maximum	5:1 maximum	
Access	Required for maintenance	Required for maintenance	
Irrigation	Simple irrigation. Only needed during droughts and plant establishment if well designed.	Complex irrigation	
Drainage	Simple drainage system	Complex drainage system	

Calculation Methods

Green roof design is governed by the water quality volume; however, special consideration must also be given to vegetation selection and proper installation with the assistance of a landscape architect or other qualified person. Special consideration must also be given to the structural design of the roof, with the assistance of a structural engineer. Neither of those considerations are taken into account in this discussion of calculation methods. For the purposes of determining if the green roof retains the water quality volume, the general design steps are:

1. Calculate the water quality volume.
2. Determine the porosity of the engineered soil used within the green roof and the retention volume within the soil.
3. Determine the required footprint to retain the water quality volume.

Sample Calculations

An extensive green roof system will be designed for a new building with a roof that is 0.37 acres. The entire roof will drain to the green roof. It's been decided that an extensive green roof system with a 6" soil matrix will be used. Determine the footprint that will be needed to capture the water quality volume.

Given
Roof area: 0.37 ac
85th percentile storm depth: 0.60 in
Porosity of engineered soil: 0.25

Determine
Determine the footprint of the green roof.

Calculations
The footprint can be determined through iterative calculations. After iterative calculations, it's found that a footprint of 3405 square feet will capture the water quality volume.

Pervious area (green roof footprint): 3405 sf (0.078 ac)
Imperviousness of rooftop: 0.79

Runoff coefficient (Reese), R_V
$R_V = (0.90)(0.79) – 0.0204$
$R_V = 0.70$

Water quality volume, WQV
WQV = (0.70)(0.60")(16117 sf)/(12 in/ft)
WQV = 562 cf

Determine the equivalent storage depth of the engineered soil.
$d_{equivalent}$ = (0.6")(0.25)
$d_{equivalent}$ = 1.5"

Determine the required footprint of the green roof to capture the water quality volume.
Footprint = WQV / $d_{equivalent}$
Footprint = 562 cf / (1.5")(12 in/ft)

Footprint = 4496 sf

Green Roof Effectiveness

Green roofs provide an aesthetically pleasing method for retaining and treating storm water runoff. Healthy plants and soils are indications that the green roof is performing as expected. Excessive drainage through the soil layer may be an indication that the soils and vegetation are not retaining runoff; consequently, the evaporation and transpiration processes are not occurring. Qualified horticulturists and/or green roof contractors should be involved in determining the health and effectiveness of the green roof.

Designer Checklist

	Yes	No
Has a landscape architect been involved in the vegetation selection?	☐	☐
Has a structural engineer been involved in the green roof design?	☐	☐
Are maintenance crews trained and aware of maintenance responsibilities?	☐	☐
Can the green roof be designed to capture the full water quality volume?	☐	☐
Will the green roof partially cover or fully cover the roof?	-	-
Will the green roof be extensive or intensive?	-	-

Vegetation Selection

Plant material selection should be based on factors determined by the type of green roof desired, structure itself, as well as the long-term maintenance the owner is able to provide. Typical green roof vegetation ranges from low-growing succulent plants (e.g., Sedums) or groundcovers (characteristic of extensive green roofs) to an assortment of native grasses, shrubs, and trees (more typical of intensive green roofs). Plants of the genus Sedum (family Crassulaceae), which are low-growing succulents, are often used for green roofs because of their resistance to wind, frost, drought, and fire. A mix of Sedum and other succulent plants is recommended because they possess many of the recommended attributes. Herbs, forbs, grasses, and other low groundcovers may also be used but typically require more irrigation and maintenance. Use of native vegetation is preferred though some natives may not thrive in the rooftop environment; thus, a mix of approximately 80% Sedum/succulent plants and 20% native plants generally recognized for their hardiness is recommended, particularly for extensive green roofs (Velazquez, 2005). Select plants that:

- Grow in a shallow and porous substrate (i.e., grasses, perennials and groundcovers are suited to roofs with a substrate of 3-7 inches minimum).
- Root system depth requirements matches depth of substrate (i.e., plants with a deeper and more extensive root system such as shrubs and some trees require 48 inches of substrate minimum depth).
- Drought tolerant and able to exist with minimal and infrequent watering, especially once established.
- Able to withstand higher wind speeds.
- Tolerant of full-sun conditions.
- Fire resistant.
- High salinity tolerance.
- Lower maintenance requirements since access is limited.
- Are primarily non-deciduous to provide adequate foliage cover year-round and reduce erosion potential
- Have good regenerative qualities (i.e., perennial or self-sowing)
- Are low maintenance (i.e., no fertilizers, pesticides, or herbicides, little or no mowing or trimming)
- Have growth patterns allowing vegetation to thoroughly cover the soil (at least 90% surface area coverage should be achieved within 2 years).
- Are compatible with the aesthetic preferences of the owner and future building occupants who may utilize the roof as a green space

Installation

Green roof installation should be done with proper oversight from qualified environmental or green roof specialists. Any requirements related to working on rooftops should be followed. During construction, vegetation and the growth media should be protected from erosion until vegetation has been established.

Additional Guidance

- Require certificates of compliance to verify that construction items meet specification requirements.

Installation Costs

The following cost items are typically associated with rain garden construction.

-Vegetation and landscaping expertise

-Horticulturist expertise

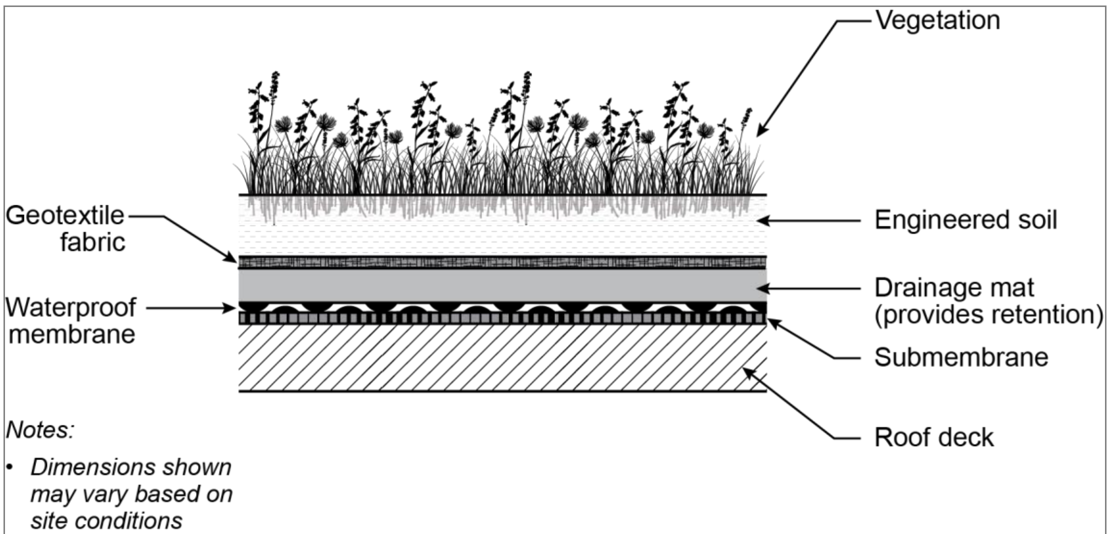
-Structural expertise

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of green roofs.

Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect weed growth.	2-4 weeks during growing season	Remove weeds before they flower.	H
Inspect fertilization.	Annually	Apply fertilizer in accordance with manufacturer recommendations. Avoid hottest/driest parts of the year.	M
Inspect water retention.	As needed	If natural precipitation is not adequate for vegetation, water plants.	H



Green Roof

Not to scale

Pervious Surfaces

PS-1

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	M
Metals*	M
Bacteria	-
Oil/Grease	H

H = High
M = Medium
L = Low
*Total metals

Pervious surfaces such as permeable pavement, concrete pavers, pervious concrete, modular open pavers, and other types of pervious surfaces provide structural support for light vehicle or pedestrian traffic while also providing open space for storm water infiltration.

Primary Functions	
Bioretention	No
Volume Retention	Yes
Filtration	Some

The primary function of pervious surfaces is volume retention, but some filtration is possible depending on the type of paver selected. A modular open paver that, when installed, provides a certain percentage of pervious area in the form of grass, will allow for filtration processes to occur. Another source of filtration is the choker layer directly beneath the pervious surface.

The subsections beneath the pervious surface are typically a choker layer composed of small gravel and a storage layer of larger rock beneath. Underdrains may be required if existing soils do not adequately infiltrate.

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters.

Parameter	Min. Value	Max. Value	Notes
Drain Time	12 hours	72 hours	
Infiltration Rate	0.5 in/hr	6 in/hr	Field testing required for final design.
Depth to Groundwater	4 ft	No maximum	

Calculation Methods

Pervious surface design is governed by the water quality volume. The general design steps are:

1. Calculate the water quality volume.
2. Determine the required thickness of the subsection layers given their porosity and the footprint of the pervious surface area.

Sample Calculations

A development in the planning phase will have a 0.90 acre parking lot. It is proposed that the parking lot be graded so that runoff is conveyed towards stalls that will be constructed with permeable asphalt.

<u>Given</u>
Contributing drainage area: 0.90 ac
Imperviousness: 0.95
85th percentile storm event: 0.53”
Soil infiltration rate: 0.5 in/hr

<u>Design Goals</u>
Determine an acceptable area size and depth of the permeable asphalt section.

<u>Calculations</u>
Runoff coefficient (Reese), R_V
$R_V = (0.91)(0.95) – 0.0204$
$R_V = 0.84$

Water quality volume, WQV
WQV = (0.84)(0.53”)(0.90 ac)(43560 sf/ac)/(12 in/ft)
WQV = 1462 cf

A permeable asphalt area that is 15’ x 140’ (2100 sf) with the following properties will retain the water quality volume and will have an acceptable drawdown time.

Layer	Thickness, in	Porosity	Storage Volume, cf
Permeable Asphalt	4	0.2	140
Choker Layer	4	0.4	280
Aggregate Storage	15	0.4	1050
Total	23	0.37 (weighted)	1470

Drawdown time, t
t = Equivalent storage depth / Infiltration rate
Weighted porosity, n_w = 0.37
Equivalent storage depth = (23")(0.37)
Equivalent storage depth = 8.4"
t = (8.4")/(0.5 in/hr)

t = 16.80 hrs

Pervious Surface Effectiveness

Pervious surfaces are effective when runoff from the design storm depth can enter the porous spaces of the pervious surface and successfully infiltrate into the native soil or drain through an underdrain system. Visual inspection of the pervious surface can reveal reasons for failure: for example, sediment-laden sheet flows that are conveyed to the pervious surface, or a down drain might be introducing organic material. Both scenarios are likely to contribute to clogging within the porous spaces of the pervious surface or within the sublayers.

Designer Checklist

	Yes	No
Will an underdrain system be required?	☐	☐
If an underdrain is needed, is there sufficient head for the underdrain system to drain?	☐	☐
Has the proposed pervious surface performed successfully in similar climate conditions?	☐	☐

Installation

Excavation
Pervious surfaces will fail if proper care is not taken during excavation and construction. Excavators and heavy machinery should not be used if infiltration is expected to occur through the underlying soils beneath the pervious surface's subsection.

Activities During Construction
Avoid using heavy machinery on the revealed soil during construction. Crews should avoid unnecessarily walking on the underlying soils when possible. Compaction of native soils or backfill below the pervious surface subsoils is acceptable if doing so does not prevent infiltration from occurring.

Flows During Construction
Flows during construction should be diverted away from the exposed underlying soil to prevent erosion. Scheduling installation of the pervious surface within a short time span after excavation will minimize the impact

of unnecessary storm water flows from entering the excavated area. The introduction of unwanted sediment and storm water flows can be prevented by placing fiber rolls or silt fences around the excavated perimeter during construction.

Additional Guidance

- Require certificates of compliance to verify that construction items meet specification requirements.

Installation Costs

The following cost items are typically associated with rain garden construction.

-Excavation

-Grading

-Fine grading

-Pervious surface

-Top layer

-Engineered soil

-Choker layer

-Open graded stone

-Geotextile fabric

-Impermeable liner

-Observation wells

-Underdrain system (if needed)

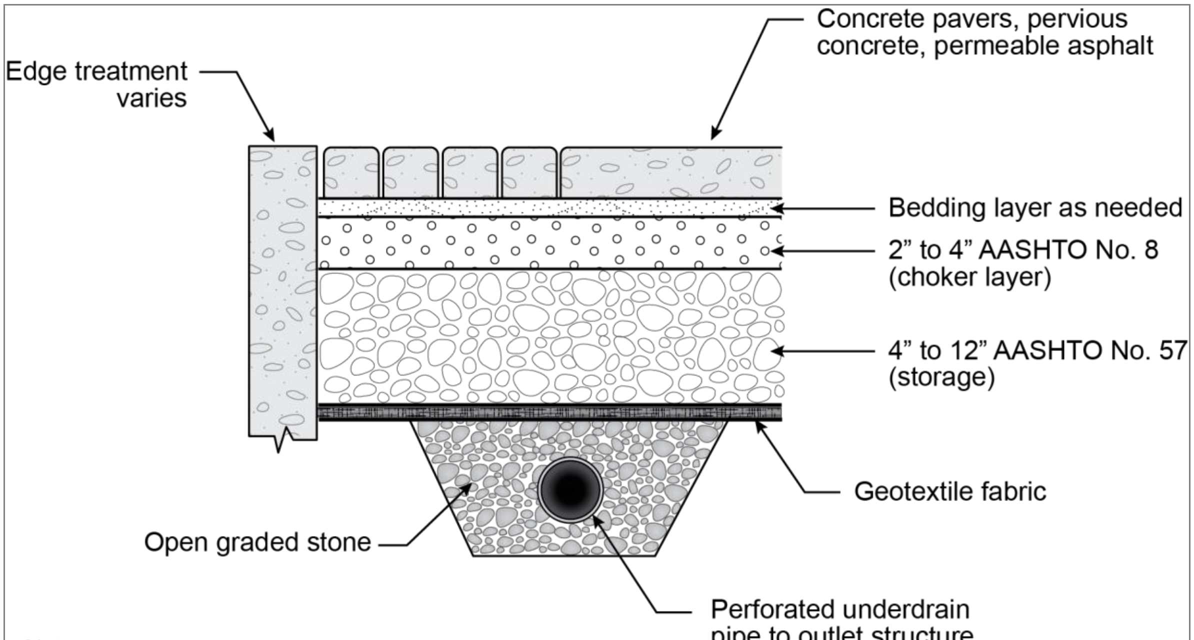
-Irrigation system (if needed)

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of pervious surfaces.

Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect for sediment accumulation.	Semiannual (Spring, Fall)	Use vacuum sweeper followed by pressure washing.	M
Inspect for weed growth.	Semiannual (Spring, Fall)	Remove weeds.	L
Inspect for standing water on surface or within observation well.	Semiannual (Spring, Fall)	Notify engineer for further inspection.	L
Inspect surface for deterioration.	Annual	Notify engineer for further inspection.	L
Inspect exfiltration and drainage performance.	As needed, at least annually	Notify engineer for further inspection.	M



Notes:

- *Dimensions shown may vary based on site conditions*

Pervious Surfaces

Not to scale

Infiltration Basin

ID-1

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	H
Metals	H
Bacteria	H
Oil/Grease	H

H = High
M = Medium
L = Low

Infiltration basins are shallow depressions that use existing soils to retain and provide treatment for storm water runoff. Infiltration basins function by capturing and infiltrating runoff over a specified drawdown time.

The primary functions of infiltration basins are bioretention, volume retention, and filtration. The existing soils perform bioretention processes and remove pollutants through physical, chemical, and biological processes before the storm water reaches the groundwater. Filtration occurs as runoff interacts with grass and other vegetation within the basin and as runoff infiltrates through the soil.

Infiltration basins are typically designed for larger drainage areas where it may be impractical for a BMP such as a bioretention area that requires more maintenance of specialized vegetation over a larger area.

Primary Functions	
Bioretention	Yes
Volume Retention	Yes
Filtration	Yes

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters.

Parameter	Min. Value	Max. Value	Notes
Water Quality Volume	0.1 ac-ft (4356 cf)	No maximum	
Freeboard	1 ft		
Overflow Spillway Length	3 ft spillway length		
Invert Slope	0% (flat basin bottom)		
Interior Side Slopes	No minimum	3H:1V	
Drawdown Time	24 hours	72 hours	48 hours recommended
Infiltration Rate	0.5 in/hr	6 in/hr	Field testing required for final design.

Calculation Methods

Infiltration basin design is governed by the water quality volume. The general design steps are:

1. Calculate the water quality volume.
2. Determine the geometry of the infiltration basin.
3. Based on the basin geometry, determine the ponding depth required to hold the water quality volume.
4. Calculate the drawdown time.

Calculate the water quality outlet elevation.

Sample Calculations

A 13.50 ac development routes all of its storm water to a single infiltration basin. A safety factor of 1.50 is required for infiltration design within the permittee's jurisdiction.

Given
Contributing drainage area: 13.50 ac
Imperviousness: 0.65
90th percentile storm depth: 0.55"
Soil infiltration rate: 1.35 in/hr

Design Goals
Determine the bottom footprint of the infiltration basin and the elevation of the water quality outlet above the basin bottom.

Calculations
Runoff coefficient (Reese), R_V
$R_V = (0.91)(0.65) - 0.0204$
$R_V = 0.57$

Water quality volume, WQV
WQV = (0.57)(0.55") (13.50 ac)(43560 sf/ac)/(12 in/ft)
WQV = 15393 cf

Minimum footprint, A_{min}
A_{min} = (12)(1.50)(15393 cf)/(1.35 in/hr)(48 hrs)
A_{min} = 4276 sf

The water quality volume will infiltrate into the existing soil in 48 hours if the infiltration basin bottom is 4276 square feet. However, this does not mean that the infiltration basin bottom is required to be 4276 square feet.

The elevation of a water quality outlet is determined by assuming that infiltration occurs only through the bottom of the basin and not through the sides.
Ele_{WQ} = WQV / A_{min}
Ele_{WQ} = 15393 cf / 4276 sf
Ele_{WQ} = 3.60 ft

Infiltration Basin Effectiveness

Effective infiltration basins take advantage of open spaces for retaining and treating storm water. Established vegetation with adequate coverage is an indication of a healthy infiltration basin along with minimal sediment and lack of invasive vegetation. Side slopes should be stable and show little to no signs of erosion or rilling. Slope sloughing is an indication that geotechnical remediation is needed.

During the design storm event, infiltration basins should, at most, pond up to the water quality outlet. After the rain event, runoff within the basin should infiltrate through the bottom soils within the design drawdown time.

Designer Checklist

	Yes	No
Does groundwater meet the minimum separation requirement?	☐	☐
Is there available right-of-way for the infiltration basin?	☐	☐
Is contaminated groundwater present at the rain garden location?	☐	☐
Is the water quality volume above the 4,356 cf threshold?	☐	☐
Can the infiltration basin be designed to retain 100% of the water quality volume?	☐	☐
Are there utility conflicts with the infiltration basin that can't be resolved?	☐	☐
Do geotechnical conditions exist that compromise the stability of nearby structures?	☐	☐
Does an overflow outlet structure exist?	☐	☐

Vegetation Selection

Refer to Vegetation Selection in the Preface to Fact Sheets.

Installation

Excavation

Installation of infiltration basins is a relatively straightforward process of excavation and grading; however, the basin will fail if proper care is not taken during construction. Excavators and heavy machinery should not be used within the basin area to avoid soil compaction.

Activities During Construction

Avoid using heavy machinery within the infiltration basin footprint during construction as doing so will compact the soils and diminish their infiltrating capabilities. Installation of an outlet structure may require machinery.

Flows During Construction

Flows during construction should be diverted away from the infiltration basin to prevent construction site sediment from clogging soils. Seeding or laying turf sod should occur within a short time span after excavation to minimize the impact of unnecessary storm water flows from entering the basin area. The introduction of unwanted sediment can be prevented by placing fiber rolls or silt fences around the basin perimeter during construction.

Additional Guidance

- Require certificates of compliance to verify that construction items meet specification requirements.
- Follow landscaping guidance to ensure that vegetation establishes after installation.

Installation Costs

The following cost items are typically associated with infiltration basin construction.

-Excavation

-Grading

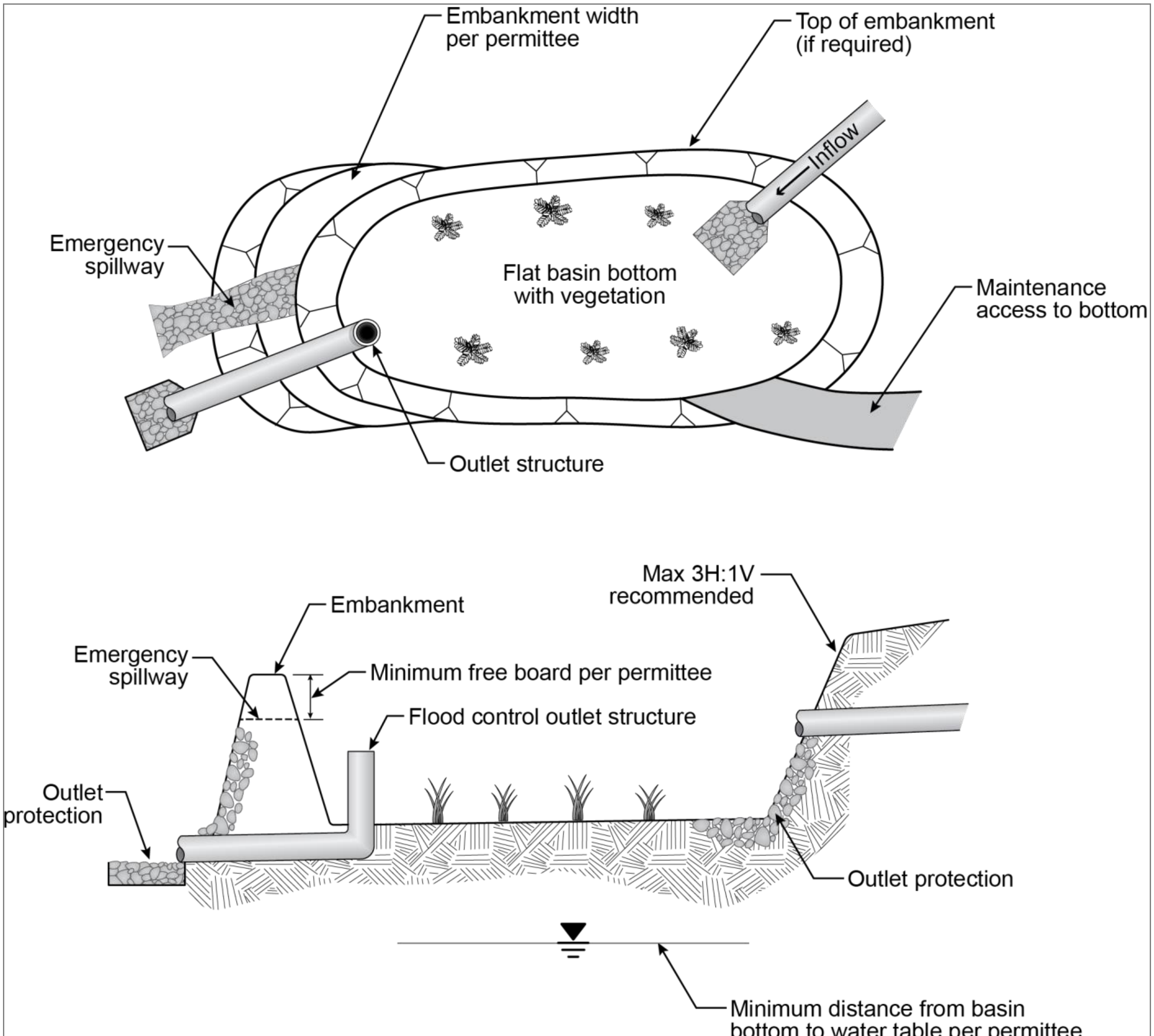
-Outlet structure

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of infiltration BMPs.

Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect for trash and debris at inlet and outlet structures.	Semiannual	Remove and dispose of trash and debris.	L
Inspect grass length.	As needed	Mow basin grass.	L
Inspect pre-treatment diversion structures for sediment build-up.	Semiannual	Remove and dispose of sediment buildup.	L
Inspect topsoil for sediment buildup.	Semiannual	Remove sediment.	L
Inspect for standing water above trench or within observation well.	Semiannual	Notify engineer for further inspection.	L



Notes:

- *Dimensions shown may vary based on site conditions*

Infiltration Basin

Not to scale

Infiltration Trench

ID-2

Source: NHDES Soak Up the Rain

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	H
Metals	H
Bacteria	H
Oil/Grease	H

H = High
M = Medium
L = Low

Infiltration trenches are linear excavations that are backfilled with a combination of gravel, open graded stone, and sand layers that provide storage within the pore space of the specified layers. Although typically linear, infiltration trenches can be any shape provided that the footprint and depth are sized to retain the water quality volume.

The primary function of infiltration trenches is volume retention. The trench is designed such that the water quality volume is retained and stored within the gravel and sand layers. Depending on the design of the trench, pollutant removal occurs via filtration as runoff passes through an initial pea gravel layer and ultimately through the bottom sand layer. A geotextile fabric is also recommended along the sidewalls of the trench and under the pea gravel layer.

Primary Functions	
Bioretention	No
Volume Retention	Yes
Filtration	Some

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters.

Parameter	Min. Value	Max. Value	Notes
Depth of Trench	2 ft	No maximum	Maximum depth determined by permittee.
Longitudinal Trench Slope	0%	1%	
Width	2 ft	No maximum	
Drawdown Time	12 hours	72 hours	
Infiltration Rate	0.5 in/hr	6 in/hr	Field testing required for final design.
Depth to Groundwater	4 ft	No maximum	

Calculation Methods

Infiltration trench design is governed by the water quality volume. The general design steps are:

1. Calculate the water quality volume.
2. Determine the trench footprint.
3. Based on the trench geometry, porosity of the trench layers, and ponding depth (if any), determine the trench depth.
4. Calculate the drawdown time.

Sample Calculations

A proposed park will have a concrete plaza that is 0.40 acres. Runoff from the plaza will flow towards a pervious area. To meet the permittee's retention requirement, the design team proposes to install an infiltration trench adjacent to the plaza.

<u>Given</u>
Contributing drainage area: 0.40 ac
Imperviousness: 1.00
90^{th} percentile storm depth: 0.70"

<u>Design Goals</u>
Determine that the geometry of an infiltration trench that will retain the water quality volume.

<u>Calculations</u>
Runoff coefficient (Reese), R_V
R_V = (0.91)(1.00) – 0.0204
R_V = 0.89

Water quality volume, WQV
WQV = (0.89)(0.70")(0.40 ac)(43560 sf/ac)/12 in/ft)
WQV = 904 cf

There are 100 linear feet adjacent to the plaza that are available for the infiltration trench. Based on the grading at the trench, ponding above the trench will not occur. A trench that is 4.5 ft wide with the following properties will be able to retain the water quality volume.

Layer	Thickness, in	Porosity	Storage Volume, cf
Pea Gravel	4	0.25	37.5
Open Graded Stone	56	0.4	840
Sand Layer	6	0.15	33.8
Total	66	0.36 (weighted)	911.2

The equivalent storage depth of the water quality volume within the 4500 sf infiltration trench is:
d = 911.2 cf / 4500 sf
d = 2 ft
d = 24 in

Drawdown time, t
The infiltration rate of the surrounding soils is 1.5 in/hr.
t = Equivalent storage depth / infiltration rate
t = 24 in / 1.5 in/hr
t = 16 hrs

Infiltration Trench Effectiveness

Effective infiltration trenches take advantage of limited right of way or narrow spaces where bioretention areas or infiltration basins are impractical. Visible sediment buildup on the top layer of the trench could be an indication that clogging is present within the trench or that runoff is simply passing over the trench and not being captured. Although some vegetation intrusion or organic debris is likely not a concern, proper grooming and maintenance will contribute to a trench's extended life-span.

During the design storm event, runoff should be conveyed toward and enter the trench per the design plans. Recent new construction, regrading, or resurfacing within the contributing drainage area should be noted as it may impact flow paths or the introduction of new pollutants.

Designer Checklist

	Yes	No
Does groundwater meet the minimum separation requirement?	☐	☐
Is the infiltration rate of the existing soils within acceptable rates?	☐	☐
Is contaminated groundwater present at the infiltration trench location?	☐	☐
Are there utility conflicts with the infiltration trench that can't be resolved?	☐	☐
Do geotechnical conditions exist that compromise the stability of nearby structures?	☐	☐
Can the infiltration trench be designed to retain 100% of the water quality volume?	☐	☐
Does an overflow outlet structure exist, if needed?	☐	☐

Vegetation Selection

Vegetation is not typical for an infiltration trench.

Installation

Excavation

Excavation for infiltration trenches is typically linear but alternate geometries are possible. During excavation, light machinery should be used to avoid excessive compaction.

Activities During Construction

Avoid using heavy machinery within the infiltration trench footprint during construction as doing so will compact the soils and diminish their infiltrating capabilities.

Flows During Construction

Flows during construction should be diverted away from the infiltration trench to prevent construction site sediment from clogging soils. The introduction of unwanted sediment can be prevented by placing fiber rolls or silt fences around the trench perimeter during construction.

Additional Guidance

- Require certificates of compliance to verify that construction items meet specification requirements.

Installation Costs

The following cost items are typically associated with infiltration trench construction.

-Excavation

-Landscaping and vegetation

-Pea gravel

-Open graded stone

-Sand layer

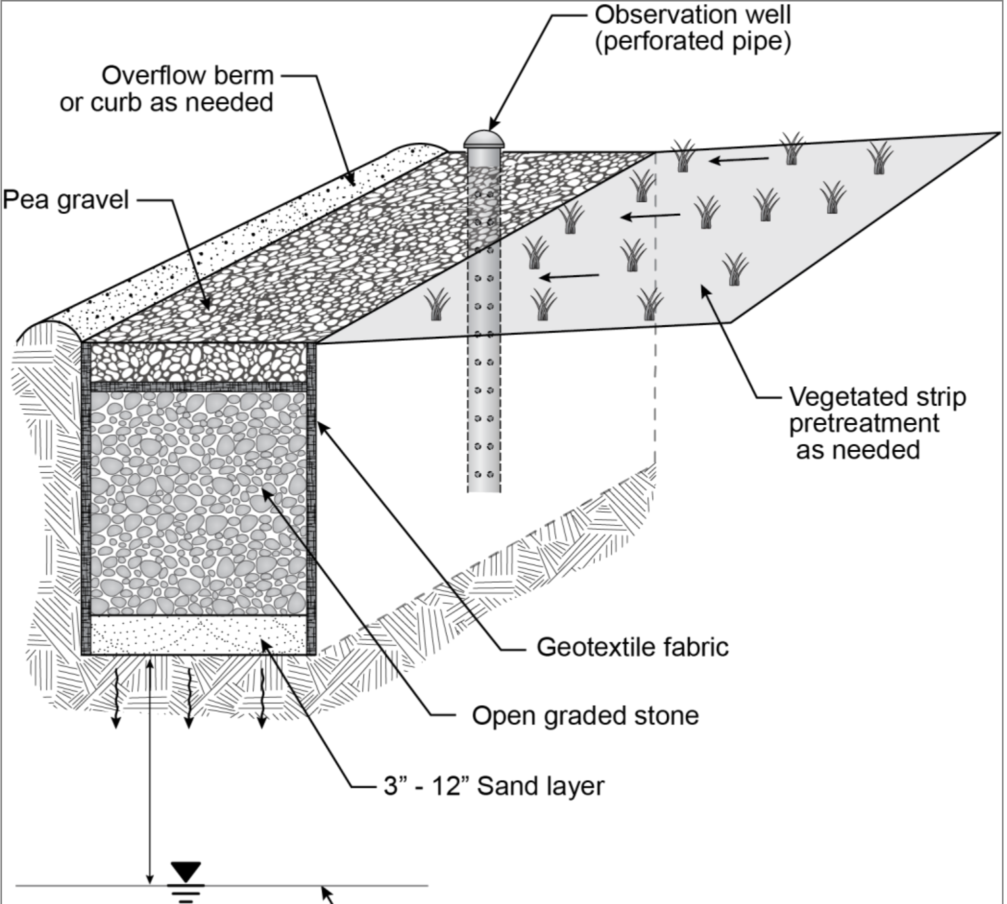
-Geotextile separator

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of infiltration BMPs.

Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect for trash and debris at inlet and outlet structures.	Semi-annual	Remove and dispose of trash and debris.	L
Inspect grass length, if any, on top of trench.	As needed	Mow trench grass.	L
Inspect pre-treatment diversion structures for sediment buildup.	Semi-annual	Remove and dispose of sediment build up.	L
Inspect tree growth near trench.	Semi-annual	Remove trees in vicinity of the trench.	L
Inspect for standing water above trench or within observation well.	Semi-Annual	Notify engineer for further inspection.	L



Notes:

- *Dimensions shown may vary based on site conditions*

Infiltration Trench

Not to scale

Dry Well

ID-3

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	H
Metals	H
Bacteria	H
Oil/Grease	H

H = High
M = Medium
L = Low

Dry wells are underground storage areas that are sized to retain the water quality volume and infiltrate runoff into the existing soils.

The primary functions of dry wells are bioretention and volume retention. Bioretention does not occur within the dry well but occurs in the native soils immediately surrounding the dry well.

Dry wells contribute to aquifer recharge and as such classify as a subclass of Underground Injection Control (UIC) Class V wells. Refer to the DWQ's website on storm water drainage wells (link below) for more information relating to the UIC Program.

Primary Functions	
Bioretention	Yes
Volume Retention	Yes
Filtration	No

Storm Water Drainage Wells: https://deq.utah.gov/legacy/programs/water-quality/utah-underground-injection-control/drainage-wells/index.htm

Design Criteria

Refer to Design Criteria in the Preface to Fact Sheets for discussion of design criteria parameters.

Parameter	Min. Value	Max. Value	Notes
Depth to Groundwater	4 ft	No maximum	
Drawdown Time	24 hours	72 hours	
Building Setback	10 ft	No maximum	
Infiltration Rate	0.5 in/hr	6 in/hr	Field testing required for final design.

Calculation Methods

Dry well design is governed by the water quality volume. The general design steps are:

1. Calculate the water quality volume.
2. Determine the dry well geometry.
3. Determine the drawdown time.

Sample Calculations

A drywell is proposed at the downstream end of a swale within a development.

Given
Contributing drainage area: 0.72 ac
Imperviousness: 0.40
90^{th} percentile storm depth: 0.59"
Infiltration rate of surrounding soil: 3 in/hr

Design Goals
Determine the dry well geometry required to hold the water quality volume.

Calculations
Runoff coefficient (Reese), R_V
$R_V = (0.91)(0.40) - 0.0204$
$R_V = 0.34$

Water quality volume, WQV
WQV = (0.34)(0.59")(0.72 ac)(43560 sf/ac)/12 in/ft)
WQV = 539 cf

A dry well that has a 7' radius and is 15' deep will hold 577 cf.

For a conservative estimate at the planning stage, the dry well's drawdown time is based on the infiltration rate of the surrounding soil and ignores the effects of the pressure head within the dry well. A more detailed determination of the drawdown should be done for final design.

Drawdown time, t
t = Dry well depth / infiltration rate
t = (15 ft)(12 in/ft) / 3 in/hr

t = 60 hrs

Dry Well Effectiveness

Effective dry wells optimize infiltrating soils within limited right of way to retain storm water runoff while not introducing stability concerns to nearby development or structures. The design storm volume within a functioning dry well will drawdown within the design time and leave no standing water inside of the well. Entry to the dry well should be unobstructed and free of debris that will restrict flows from entering.

Designer Checklist

	Yes	No
Does groundwater meet the minimum separation requirement?	☐	☐
Is the infiltration rate of the existing soils within acceptable rates?	☐	☐
Is contaminated groundwater present at the dry well location?	☐	☐
Are there utility conflicts with the dry well that can't be resolved?	☐	☐
Do geotechnical conditions exist that compromise the stability of nearby structures?	☐	☐
Is pretreatment provided upstream of or within the dry well?	☐	☐

Installation

Excavation
Excavate area in which dry well will be placed.

Activities During Construction
Take proper safety measures to cover the excavated dry well area before putting the dry well in place. If the dry well is designed to infiltrate through the well bottom, place and level gravel within the excavation to provide a foundation for the well structure.

Flows During Construction
Flows during construction can enter the dry well if the grated manhole lid contains a filtering material.

Additional Guidance

- Require certificates of compliance to verify that construction items meet specification requirements.
- Obtain a permit through the UIC Program

Installation Costs

The following cost items are typically associated with dry well construction.

-Excavation

-Dry well

-Permit application fees for Class V Injection Wells

-Gravel-filled annular space surrounding dry well

-Pretreatment upstream of dry well

-Overflow connection to downstream system

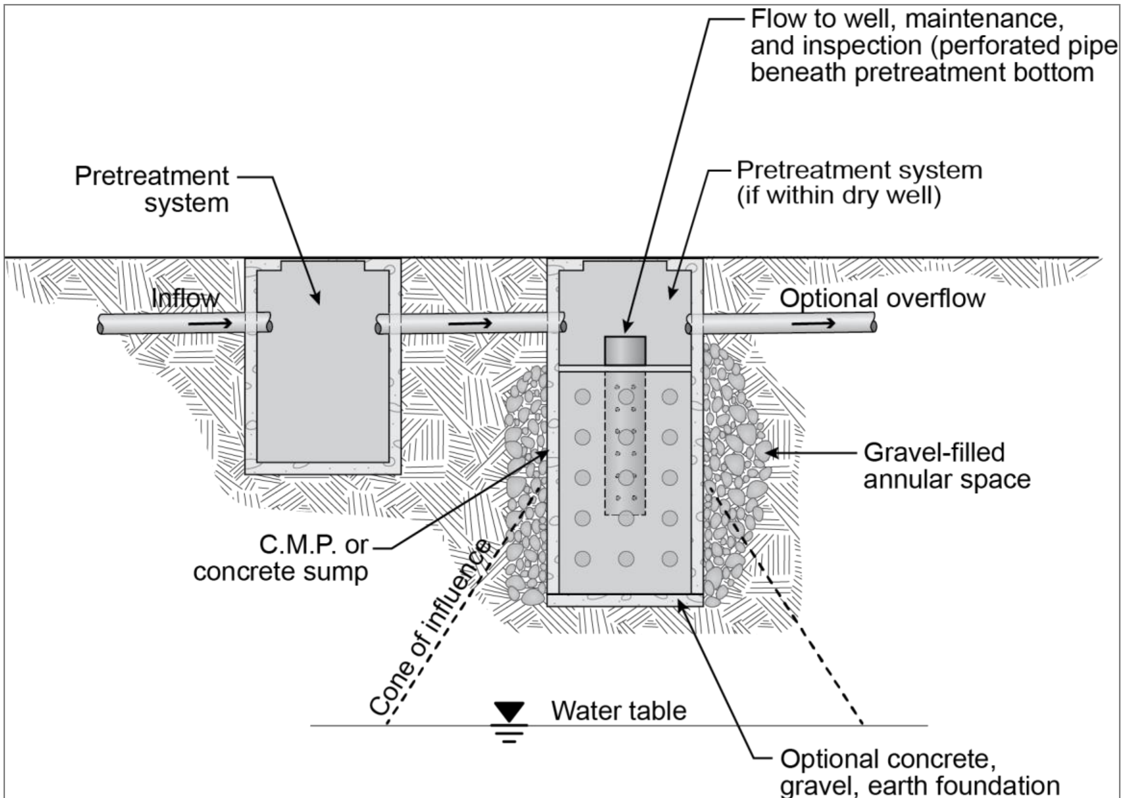
-Gravel foundation (optional)

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of dry wells.

Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect water depth.	Initially after every major storm, then annually.	Remove and dispose of built up sediment when buildup causes reduction in detention capacity. Notify the engineer.	M
Inspect inlet for obstructions.	Semi-annual	Remove obstructions.	L
Inspect structural elements.	As determined by permittee.	Repair or reconstruct deficient structural components.	M



Notes:

- *Dimensions shown may vary based on site conditions*

Dry Wells

Not to scale

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Underground Infiltration Galleries *ID-4*

Source: StormTech

Pollutant Removal Effectiveness

Pollutant	Effectiveness
Sediment	H
Nutrients	H
Metals	H
Bacteria	H
Oil/Grease	H

H = High
M = Medium
L = Low

Underground storage devices are proprietary alternatives to above ground storage when space at the project site is limited. They may be sized for the 90th percentile volume similar to how they are sized for flood control volumes. When underground storage is used for water quality, its primary functions are bioretention as runoff infiltrates into the underlying soil and volume retention. They are constrained by subsurface conditions such as depth to groundwater, soil infiltration rates, and other site-specific constraints that prevent infiltration. Designing underground storage devices is done with the assistance of the device manufacturer.

Primary Functions	
Bioretention	Yes
Volume Retention	Yes
Filtration	No

Pretreatment for underground systems will vary. Pretreatment removes sediment that will potentially clog elements of the underground system such as geotextile fabrics or bedding layers. If the manufacturer does not include a pretreatment system as part of the device, it may be necessary to design a separate pretreatment system such as a settling basin upstream before entering the underground system.

Underground systems are typically modular and allow for configurations that range from large areas such as would be needed underneath a parking lot to linear installations like within a park strip or underneath a bioswale.

Design Criteria

Underground storage devices are proprietary devices; follow manufacturer specifications to determine design criteria on a case-by-case basis.

Calculation Methods

Underground storage device design is governed by the water quality volume (when sizing for the water quality event). It is not uncommon for manufacturers to provide sizing tools based on the desired storage volume. The general design steps are:

1. Calculate the water quality volume.

2. Determine manufacturer's recommendations given the water quality volume and other site conditions.

Underground Infiltration Effectiveness

With regular maintenance and inspection, it can be determined if the underground system is performing as expected. As part of the design process, determine how the system will be inspected. Possible inspection methods include the use of observation wells or structural vaults at tie-in locations with the site's storm drain network. Inspect for any soil displacement or movement at the perimeter of the system and any depressions above the system.

Designer Checklist

	Yes	No
Does groundwater meet the minimum separation requirement?	☐	☐
Is the infiltration rate of the existing soils within acceptable rates?	☐	☐
Is contaminated groundwater present?	☐	☐
Are there utility conflicts that can't be resolved?	☐	☐
Do geotechnical conditions exist that compromise the stability of nearby structures?	☐	☐
Is pretreatment provided upstream of or within the underground storage device?	☐	☐
Is the soil bearing capacity of the underlying soil sufficient for the system?	☐	☐
Will the underground system support the expected loads above it?	☐	☐

Installation

Excavation
Excavate the footprint of the underground system.

Activities During Construction
Avoid using heavy machinery within the excavated footprint during construction as doing so will compact the soils and diminish their infiltrating capabilities. Avoid using heavy machinery on top of the underground system as well. Follow all installation guidelines from the manufacturer.

Flows During Construction

Flows during construction should be diverted away from the excavated area to prevent construction site sediment from clogging soils.

Additional Guidance

- Follow all manufacturer's requirements.

Installation Costs

The following cost items are typically associated with installation of underground storage systems.

-Excavation

-Geotextile fabric

-Underground storage devices

-Aggregate (bedding, overlay, other as needed)

-Observation wells

-Pretreatment upstream of system (if not provided)

Maintenance

Underground systems are typically designed with accessible pretreatment areas such as a manhole. Refer to manufacturer's guidelines.

Maintenance Activities

Typical maintenance activity includes removal of sediment or debris within the pretreatment area. High pressure washing of geotextile fabrics or replacement of filter fabrics may also be needed. Refer to manufacturer's guidelines for specific activities and frequency of inspections.

Manufacturers

The following table of manufacturers is for reference only and does not constitute an endorsement.

Manufacturer	Device Type(s)	URL
StormTech	Chambers	http://www.stormtech.com/
ACF Environmental	Chambers R Tanks	https://www.acfenvironmental.com
ConTech	Chambers	https://www.conteches.com

Harvest and Reuse

HR-1

Pollutant Removal Effectiveness

Pollutant removal will vary based on the ultimate use of the harvested runoff.

Harvest and reuse refers to any type of runoff collection system that captures rainfall, stores it temporarily, and reuses it for irrigation, landscaping, or other non-potable uses. Harvest and reuse systems inherently retain the volume of runoff that it captures. Depending on the subsequent use after being captured, they also provide bioretention and filtration to the released runoff.

Harvest and reuse systems may be used in lieu of directly connecting rooftop drains to storm sewer systems; where downdrains discharge to impervious surfaces and the opportunity for irrigation or landscaping exists; as part of a home owner's irrigation plan; or for any other non-potable purpose where storm water is determined to be acceptable such as vehicle or machinery washing.

As of 2010, Utah's legislative code 73-3-1.5 requires that if more than 100 gallons of rainwater (13.4 cf) are captured, it must be registered through the Utah Division of Water Rights (https://waterrights.utah.gov/forms/rainwater.asp). The code also limits the total capture to 2500 gallons (334.2 cubic feet). See the code for additional requirements.

Primary Functions	
Bioretention	Varies
Volume Retention	Yes
Filtration	Varies

Design Criteria

Design criteria for harvest and reuse devices or systems will vary widely. The governing principles of harvest and reuse are based on the system's function and capacity. For example, a rain barrel that provides occasional irrigation to a flower bed should be appropriately sized for the 90th percentile volume and also be able to release the volume within an appropriate time that does not flood out the flower bed. A larger harvest and reuse systems, such as an underground detention vault or above ground pond will be required to meet geotechnical or structural design criteria. The applications of harvest and reuse systems are endless; specific design criteria should be determined on a case-by-case basis with site-specific consideration.

Calculation Methods

Harvest and reuse systems are governed by the water quality volume. The general design steps are:

1. Calculate the water quality volume.
2. Size device for the water quality volume.

Sample Calculations

A commercial development will have two buildings with roofs that are 2,500 square feet each. Rain barrels that will release to flower beds will be included as part of the design. Each roof is considered one drainage area.

<u>Given</u>
Contributing drainage area: 2500 sf
Contributing drainage area: 0.057 ac
Imperviousness: 1.00
90th percentile storm depth: 0.60 inches

<u>Design Goals</u>
Capture all runoff from the 90th percentile storm within rain barrels.

<u>Calculations</u>
Runoff coefficient (Reese), R_V
$R_V = (0.91)(1.00) – 0.0204$
$R_V = 0.89$

Water quality volume, WQV
WQV = (0.89)(0.60") (0.057 ac)(43560 sf/ac)/(12 in/ft)
WQV = 111 cf
WQV = 832 gallons

If 55-gallon rain barrels are used, 15 rain barrels will be needed for each roof and the capture will need to be registered with the Division of Water Rights.

Harvest and Reuse Effectiveness

The effectiveness of a harvest and reuse system is dependent on its use. Detention devices should be free of standing water to prevent stagnation and vector concerns. Systems that provide irrigation or that are part of landscaping features should be inspected regularly to ensure proper performance.

Designer Checklist

	Yes	No
Will stagnation of runoff be prevented by frequent release of the harvested runoff?	☐	☐
Does quantity of harvested runoff require registration with the Division of Water Rights?	☐	☐

Installation

Installation of harvest and reuse systems will vary depending on its use. Rain barrels can simply be connected to a down drain. More complicated systems require additional coordination.

Depending on the quantity of runoff being harvested, it will be necessary to register the detention device with the Division of Water Rights.

Installation Costs

The following cost items are typically associated with harvest and reuse systems.

-Detention device

-Upstream connection to detention device

-Connecting system dependent on site-specific use

Maintenance

Refer to Maintenance and Maintenance Costs in the Preface to Fact Sheets for general information related to maintenance of bioretention BMPs.

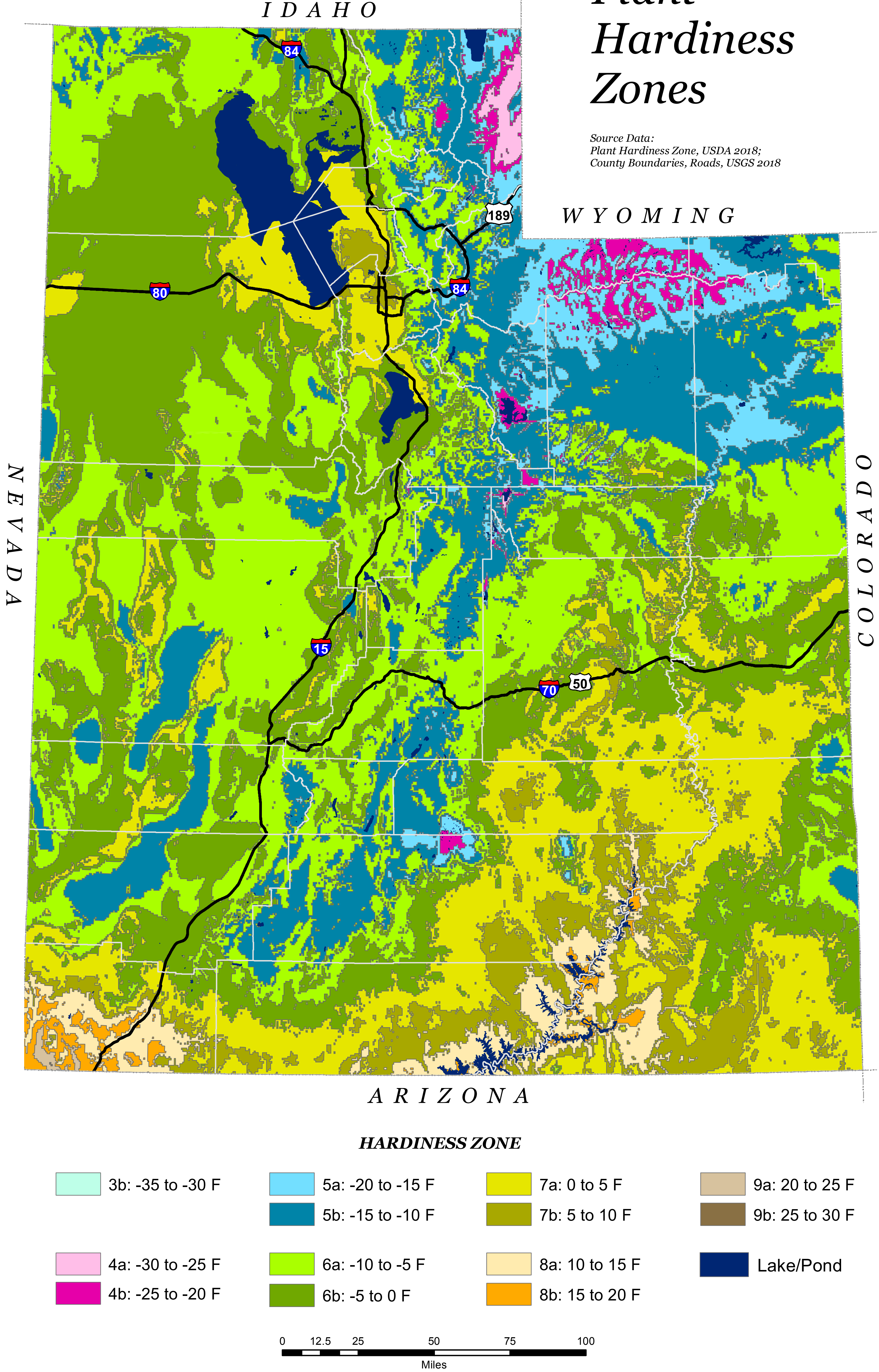
Maintenance Activities

Inspection	Inspection/Maintenance Frequency	Maintenance Activity	Effort
Inspect for mosquitos.	Semiannual	Implement larvicide or other remediation.	L
Inspect harvesting device for leaking.	Semiannual	Replace harvesting device.	L
Inspect condition of system components.	Semiannual	Replace and repair components.	M

Appendix C Utah Plant Hardiness Zones

Plant Hardiness Zones

Source Data:
Plant Hardiness Zone, USDA 2018;
County Boundaries, Roads, USGS 2018



HARDINESS ZONE

- 3b: -35 to -30 F
- 4a: -30 to -25 F
- 4b: -25 to -20 F
- 5a: -20 to -15 F
- 5b: -15 to -10 F
- 6a: -10 to -5 F
- 6b: -5 to 0 F
- 7a: 0 to 5 F
- 7b: 5 to 10 F
- 8a: 10 to 15 F
- 8b: 15 to 20 F
- 9a: 20 to 25 F
- 9b: 25 to 30 F
- Lake/Pond

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Appendix D Utah Plant Selection Matrix by Climate Zone and BMP

Plants		Zones													Best Management Practices (BMPs)					
Trees	**Common Name**	**3b**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**	**7a**	**7b**	**8a**	**8b**	**9a**	**9b**	**Basins**	**Swales**	**Strips**	**Bioretention Cells/ Rain Gardens**	**Tree Box Filters**	**Green Roofs**
Acer x feemanii 'Jeffersred'	Autumn Blaze Maple	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	
Acer campestre	Hedge Maple		x	x	x	x	x	x	x	x	x	x					x			
Acer campestre 'Carnival'	Carnival Hedge Maple		x	x	x	x	x	x	x	x	x	x					x			
Acer ginnala	Amur Maple	x	x	x	x	x	x	x	x	x	x				x	x		x	x	
Acer glabrum	Rocky Mountain Maple				x	x	x	x	x	x	x	x	x	x						
Acer negundo 'Sensation'	Sensation Boxelder		x	x	x	x	x	x							x	x		x	x	
Acer palmatum species	Japanese Maples				x	x	x	x	x	x	x	x					x			
Acer platanoides	Norway Maple		x	x	x	x	x	x	x	x							x			
Acer platanoides 'Columnare'	Columnar Norway Maple		x	x	x	x	x	x	x	x							x			
Acer platanoides 'Crimson Sentry'	Crimson Sentry Norway Maple	x	x	x	x	x	x	x	x	x							x			
Acer pseudoplatanus 'Spaethii'	Purple Sycamore Maple				x	x	x	x	x	x	x	x	x	x			x			
Acer pseudoplatanus 'Tunpetti' Regal Petticoat	Regal Petticoat Sycamore Maple		x	x	x	x	x	x	x	x	x	x	x	x			x			x
Acer rubrum	Red Maple	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Acer saccharinum	Silver Maple		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
Acer tataricum	Tatarian Maple	x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	
Acer tataricum 'GarAnn' PP 15,023	HOT WINGS® Tatarian maple		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	
Acer tataricum ssp. Ginnala	Amur Maple	x	x	x	x	x	x	x	x	x	x	x					x			
Aesculus hippocastanum	Horsechestnut	x	x	x	x	x	x	x	x	x	x	x					x			
Alnus rubra	Red Alder		x	x	x	x												x		
Alnus incana sp. Tenufolia	Thinleaf Alder	x	x	x	x	x												x		
Alnus sinuata	Sitka Alder		x	x	x	x									x	x		x		
Amelanchier laevis 'Spring Flurry'	Spring Flurry Serviceberry	x	x	x	x	x	x	x									x			
Betula nigra	River Birch		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		
Betula occidentalis	Water Birch	x	x	x	x	x												x		
Betula papyrifera	Paper Birch	x	x	x	x	x	x	x										x		
Betula pendula	Silver Birch	x	x	x	x	x	x	x										x		
Betula pubescens	White Birch	x	x	x	x	x	x	x										x		
Carpinus betulus 'Fastigiata'	Pyramidal European Hornbeam		x	x	x	x	x	x	x	x	x	x					x			
Catalpa speciosa	Catalpa				x	x	x	x	x	x	x	x	x	x	x	x	x			x
Catalpa x erubescens 'Purpurea'	Purple Catalpa				x	x	x	x	x	x	x	x	x	x						
Celtis occidentalis	Common Hackberry		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x		
Celtis occidentalis 'Prairie Pride'	Prairie Pride Hackberry	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		
Cercis canadensis	Eastern Redbud				x	x	x	x	x	x	x	x	x	x			x			
Cercis canadensis 'The Rising Sun'	Rising Sun Redbud				x	x	x	x	x	x	x	x	x	x			x			
Cercis canadensis 'Ruby Falls'	Ruby Falls Redbud						x	x	x	x	x	x	x	x			x			
Chilopsis linearis	Desert Willow								x	x	x	x	x	x			x			
Corylus colurna	Turkish Filbert			x	x	x	x	x	x	x					x	x	x			
Crataegus arnoldiana	Arnold Hawthorn				x	x	x	x	x	x	x	x	x	x	x	x				
Crataegus douglasii	Black/ Douglas Hawthorn		x	x	x	x	x	x										x		
Crataegus laevigata	English Hawthorn		x	x	x	x	x	x	x	x	x	x			x	x	x			
Crataegus phaenopyrum	Washington Hawthorn		x	x	x	x	x	x	x	x	x	x					x			
Fagus grandifolia	American Beech	x	x	x	x	x	x	x	x	x	x	x	x	x						
Fraxinus pennsylvanica	Green Ash	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x			
Ginkgo biloba 'Fairmount'	Fairmount Ginkgo				x	x	x	x	x	x	x	x					x			
Ginkgo biloba 'PNI 2720'	Princeton Sentry Ginkgo	x	x	x	x	x	x	x	x	x	x	x					x			
Gleditsia triacanthos 'Impcole' Imperial	Imperial Honeylocust		x	x	x	x	x	x	x	x	x	x					x			
Gleditsia triacanthos 'Imperial'	Imperial Honey Locust		x	x	x	x	x	x	x	x	x	x					x			
Gleditsia triacanthos 'Shademaster'	Shademaster Honeylocust				x	x	x	x	x	x	x	x					x			
Gleditsia triacanthos 'Skyline'	Skyline Honelocust	x	x	x	x	x	x	x	x	x	x	x					x			
Gleditsia triacanthos var. inermis 'Suncole'	Sunburst Honey Locust	x	x	x	x	x	x	x	x	x	x	x					x			
Gymnocladus dioica	Kentucky Coffeetree				x	x	x	x	x	x	x	x	x	x				x		
Koelreuteria paniculate	Golden Raintree				x	x	x	x	x	x	x	x	x	x			x			
Koelreuteria paniculate	Golden Raintree				x	x	x	x	x	x	x	x	x	x			x			
Liriodendron tulipifera 'Aureomarginatum'	Majestic Beauty Tulip Tree				x	x	x	x	x	x	x	x	x	x	x					
Liriodendron tulipifera 'Fastigiatum'	Columnar Tulip Tree				x	x	x	x	x	x	x	x	x	x	x					
Maackia amurensis	Amur Maackia	x	x	x	x	x	x	x	x	x							x			
Malus 'Adams'	Adams Crabapple		x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Malus 'Prairifire'	Prairifire Crabapple				x	x	x	x	x	x	x	x			x	x				
Malus 'Spring Snow'	Spring Snow Crabapple				x	x	x	x	x	x	x	x			x	x				
Malus 'Weepcanzam'	Candied Apple Crabapple		x	x	x	x	x	x	x	x	x	x			x	x				
Malus 'JFSKW213MZ'	Raspberry Spear Upright Crabapple		x	x	x	x	x	x	x	x					x	x				
Malus 'JFS-KW5' Royal Raindrops	Royal Raindrops Crabapple		x	x	x	x	x	x	x	x	x	x	x	x	x	x				

Plants		Zones													Best Management Practices (BMPs)					
Trees	**Common Name**	**3b**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**	**7a**	**7b**	**8a**	**8b**	**9a**	**9b**	**Basins**	**Swales**	**Strips**	**Bioretention Cells/ Rain Gardens**	**Tree Box Filters**	**Green Roofs**
Malus 'Royalty'	Royalty Crabapple				x	x	x	x	x	x	x	x			x	x				
Malus pumila 'Obelisk' Stark Crimson Spire	Stark Crimson Spire Apple		x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Malus pumila 'Tuscan' Stark Emerald Spire	Stark Emerald Spire Apple		x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Malus sargentii 'Tina'	Tina Sargent Crabapple		x	x	x	x	x	x	x	x	x	x			x	x				
Platanus x acerifolia	London Plane Tree (American Sycamore)		x	x	x	x	x	x	x	x	x	x						x		
Platanus x hispanica	London Plane Tree		x	x	x	x	x	x	x	x	x	x						x		
Populus angustifolia	Narrowleaf Cottonwood	x	x	x	x	x	x	x	x	x	x	x			x	x		x		
Populus fremontii	Fremont Cottonwood		x	x	x	x	x	x							x	x		x		
Populus tremuloides	Quaking Aspen	x	x	x	x	x	x	x							x	x				
Populus trichocarpa	Black Cottonwood		x	x	x	x	x	x										x		
Prunus americana	American Plum	x	x	x	x	x	x	x	x	x	x	x			x	x				
Prunus maackii	Amur Chokecherry	x	x	x	x	x	x	x							x	x				
Prunus padus	Bird Cherry	x	x	x	x	x	x	x									x			
Pyrus calleryana 'Chanticleer'	Chanticleer Flowering Pear				x	x	x	x	x	x	x	x	x	x			x			
Quercus 'Clemson' Heritage	Heritage Oak		x	x	x	x	x	x	x	x	x				x	x				
Quercus bicolor	Swamp White Oak	x	x	x	x	x	x	x	x	x	x	x			x	x	x	x		
Quercus gambelii	Gambel Oak		x	x	x	x	x	x	x	x	x	x			x	x				
Quercus macrocarpa	Bur Oak	x	x	x	x	x	x	x	x	x	x	x			x	x		x		
Quercus robur	English Oak				x	x	x	x	x	x	x	x			x	x				
Quercus robur f. fastigiata	Columnar English Oak				x	x	x	x	x	x	x	x			x	x	x			
Quercus rubra	Northern Red Oak				x	x	x	x	x	x	x	x			x	x	x			
Quercus undulata	Wavyleaf Oak				x	x	x	x	x	x	x	x			x	x				
Robinia 'Purple Robe'	Purple Robe Locust	x	x	x	x	x	x	x	x	x	x	x					x			
Salix alba	White Willow		x	x	x	x									x	x		x		
Salix amygdaloides	Peachleaf Willow		x	x	x	x												x		
Salix lasiandra	Pacific Willow	x	x	x											x	x		x		
Salix nigra	Black Willow	x	x	x	x	x									x	x		x		
Salix sitchensis	Sitka Willow		x	x	x										x	x		x		
Salix prolixa	Mackenzie Willow		x	x	x	x									x	x		x		
Sambucus coerulea	Blue Elderberry		x	x	x	x	x	x							x	x		x		
Sambucus racemosa 'SMNSRD4' Lemony Lace	Lemony Lace Elderberry	x	x	x	x	x	x	x	x	x								x		
Sambucus racemosa 'Sutherland Gold'	Sutherland Gold Elderrberry	x	x	x	x	x	x	x	x	x	x	x						x		
Shepherdia argentea	Silver Buffaloberry	x	x	x	x	x	x	x										x		
Sophora japonica 'Halka'	Millstone Japanese Pagoda Tree				x	x	x	x	x	x	x	x					x			
Sophora japonica 'Regent'	Regent Japanese Pagodatree				x	x	x	x	x	x	x						x			
Syringa reticulata 'Ivory Silk'	Ivory Silk Tree Lilac	x	x	x	x	x	x	x	x	x							x			
Taxodium distichum	Bald Cypress		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Taxodium distichum 'Shawnee Brave'	Shawnee Brave Bald Cypress		x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	
Tilia cordata 'Greesnspire'	Greenspire Linden		x	x	x	x	x	x	x	x	x	x					x			
Tilia tomentosa	Silver Linden		x	x	x	x	x	x	x	x	x	x					x			
Tilia tomentosa 'Sterling'	Sterling Silver Linden		x	x	x	x	x	x	x	x	x						x			
Ulmus 'Frontier'	Frontier Elm				x	x	x	x	x	x	x	x	x	x			x			
Ulmus 'Homestead'	Homestead Elm	x	x	x	x	x	x	x	x	x	x	x	x	x			x	x		
Ulmaus parvifolia 'Emer II' Allee	Allee Lacebark Elm		x	x	x	x	x	x	x	x	x	x	x	x			x			x
Ulmus pumila	Siberian Elm		x	x	x	x	x	x	x	x	x	x	x	x	x	x				x
Ulmus x 'Morton' Accolade	Accolade Elm			x	x	x	x	x	x	x	x	x	x	x			x			
Zelkova serrata	Japanese Zelkova				x	x	x	x	x	x	x	x					x			
Zelkova serrata 'Green Vase'	Green Vase Zelkova				x	x	x	x	x	x	x	x	x				x			
Zelkova serrata 'Kiwi Sunset'	Kiwi Sunset Zelkova				x	x	x	x	x	x	x	x					x			
Zelkova serrata 'Village Green'	Village Green Zelkova				x	x	x	x	x	x	x	x					x			
Conifers																				
Cedrus libani 'Beacon Hill'	Beacon Hill Cedar of Lebanon						x	x	x	x					x					
Juniperus osteosperma	Utah Juniper	x	x	x	x	x	x	x	x	x					x	x	x			x
Juniperus scopulorum 'Blue Arrow'	Blue Arrow Juniper		x	x	x	x	x	x	x	x	x	x	x	x	x	x				x
Juniperus scopulorum 'Skyrocket'	Skyrocket Juniper	x	x	x	x	x	x	x	x	x	x	x			x	x				x
Juniperus scopulorum 'Woodward'	Woodward columnar juniper	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus virginiana 'Blue Arrow'	Blue Arrow Eastern Red Cedar		x	x	x	x	x	x	x	x	x	x	x	x	x	x				x
Juniperus virginiana 'Hillspire'	Hillspire Eastern Red Cedar	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x
Picea pungens	Colorado Spruce	x	x	x	x	x	x	x	x	x	x	x			x	x				
Pinus mugo	Mugo Pine	x	x	x	x	x	x	x	x	x					x	x				x
Pinus mugo 'Carsten's Wintergold'	Carsten's Wintergold Mugo Pine	x	x	x	x	x	x	x	x	x					x	x				x
Pinus mugo 'Jakobsen'	Pinus mugo 'Jakobsen'	x	x	x	x	x	x	x	x	x					x	x				x

Plants		Zones													Best Management Practices (BMPs)					
Trees	Common Name	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b	Basins	Swales	Strips	Bioretention Cells/ Rain Gardens	Tree Box Filters	Green Roofs
Pinus ponderosa	Ponderosa Pine	x	x	x	x	x	x	x	x	x					x	x				
Pinus strobus 'Blue Shag'	Blue Shag Eastern White Pine		x	x	x	x	x	x	x	x	x	x			x	x				
Pinus strobus 'Pendula'	Weeping White Pine	x	x	x	x	x	x	x	x	x	x	x								

Plants		Zones													Best Management Practices (BMPs)					
Shrubs	**Common Name**	**3b**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**	**7a**	**7b**	**8a**	**8b**	**9a**	**9b**	**Basins**	**Swales**	**Strips**	**Bioretention Cells/ Rain Gardens**	**Tree Box Filters**	**Green Roofs**
Amelanchier alnifolia	Saskatoon Serviceberry	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Amelanchier alnifolia 'Obelisk'	Standing Ovation Serviceberry	x	x	x	x	x	x	x	x	x	x	x				x		x		
Aronia arbutifolia 'Brilliantissima'	Brilliant Red Chokeberry		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Aronia melanocarpa var. elata	Black Chokeberry		x	x	x	x	x	x	x	x	x	x	x	x	x			x	x	
Atriplex canescens	Four-Wing Saltbrush						x	x	x	x	x	x	x	x	x	x				
Caragana arborescens	Siberian Peashrub	x	x	x	x	x	x	x	x	x	x	x			x	x				x
Caragana arborescens 'Pendula'	Weeping Pea Shrub	x	x	x	x	x									x	x				x
Celtis occidentalis	Common Hackberry		x	x	x	x	x	x	x	x	x	x	x	x			x	x	x	
Cornus sanguinea 'Midwinter Fire'	Midwinter Fire Dogwood				x	x	x	x	x	x								x	x	
Cornus sericea	Red Twig Dogwood	x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	
Cornus sericea 'Baileyi'	Bailey Red Twig Dogwood	x	x	x	x	x	x	x	x	x	x	x						x	x	
Cornus sericea 'Budd's Yellow'	Budd's Yellow Dogwood	x	x	x	x	x	x	x	x	x								x	x	
Cornus sericea 'Cardinal'	Cardinal Red Twig Dogwood	x	x	x	x	x	x	x	x	x	x	x						x	x	
Cornus sericea 'Farrow'	Artic Fire Dogwood	x	x	x	x	x	x	x	x	x								x	x	
Cornus sericea 'Flaviramea'	Yellow Twig Dogwood	x	x	x	x	x	x	x	x	x	x	x						x	x	
Cornus sericea 'Isanti'	Isanti Red Twig Dogwood	x	x	x	x	x	x	x	x	x	x	x						x	x	
Cornus sericea 'Kelseyi'	Kelsey's Dwarf Red Twig Dogwood	x	x	x	x	x	x	x	x	x	x	x						x	x	
Cornus stolonifera 'Neil Z' Pucker Up	Pucker Up Red Twig Dogwood	x	x	x	x	x	x	x	x	x	x	x			x	x		x	x	
Cotoneaster integerrimus	European Cotoneaster	x	x	x	x	x									x	x				
Forsythia x 'Meadlowlark"	Meadowlark Forsythia	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Forsythia x 'New Hampshire Gold'	New Hampshir Gold Forsythia	x	x	x	x	x	x	x	x	x	x	x								
Forsythia 'Northern Gold'	Northern Gold Forsythia	x	x	x	x	x	x	x	x	x	x	x								
Genista lydia 'Select' Bangle	Bangle Dyers Greenwood		x	x	x	x	x	x	x	x	x	x	x	x						
Gutierrezia sarothrae	Snakebrush		x	x	x	x	x	x	x	x	x	x	x	x						
Hamamelis x intermedia 'Arnold's Promise'	Arnold's Promise Witch Hazel				x	x	x	x	x	x	x	x								
Helianthemum 'Ben Ledi'	Ben Ledi Sun Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Helianthemum 'Ben More'	Ben More Sun Rose				x	x	x	x	x	x	x	x	x	x						
Helianthemum 'Cheviot'	Cheviot Sun Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Helianthemum 'Dazzler'	Dazzler Sun Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Helianthemum 'Henfield Brilliant'	Henfield Brilliant Sun Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Helianthemum 'Raspberry Ripple'	Raspberry Ripple Sun Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Helianthemum 'Rhodanthe Carneum'	Rhodanthe Carneum Sun Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Helianthemum 'St. Mary's'	St Mary's Sun Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Helianthemum 'Wisley Primrose'	Wisley Primrose Sun Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Heptacodium miconioides	Seven Son Flower				x	x	x	x	x	x	x	x								
Hibiscus 'Rose Mallow'	Fireball Hardy Hibiscus		x	x	x	x	x	x	x	x	x	x	x	x						
Hibiscus 'Summer Storm'	Summer Storm Hardy Hibiscus		x	x	x	x	x	x	x	x	x	x	x	x						
Hibiscus syriacus 'Aphrodite'	Aphrodite Rose of Sharon				x	x	x	x	x	x	x	x								
Hibiscus syriacus 'Blue Bird'	Blue Bird Rose of Sharon				x	x	x	x	x	x	x	x								
Hibiscus syriacus 'Blushing Bride'	Blushing Bride Rose of Sharon				x	x	x	x	x	x	x	x								
Hibiscus syriacus 'Coelestis'	Coelestis Rose of Sharon				x	x	x	x	x	x	x	x	x							
Hibiscus syriacus 'Collie Mullens'	Collie Mullens Rose of Sharon				x	x	x	x	x	x	x	x								
Hibiscus syriacus 'Diana'	Diana Rose of Sharon	x	x	x	x	x	x	x	x	x										
Hibiscus syriacus 'Helene'	Helene Rose of Sharon				x	x	x	x	x	x	x	x								
Hibiscus syriacus 'Jeanne d'Arc'	Jeanne d'Arc Rose of Sharon				x	x	x	x	x	x	x	x								
Hibiscus syriacus 'Minerva'	Minerva Rose of Sharon				x	x	x	x	x	x	x	x								
Hibiscus syriacus 'Paeoniflorus'	Peony Flowered Rose of Sharon					x	x	x	x	x	x	x	x							
Hibiscus syriacus 'Red Heart'	Red Heart Rose of Sharon				x	x	x	x	x	x	x	x								
Holodiscus discolor	Oceanspray				x	x	x	x	x	x	x	x	x	x						
Hydrangea paniculata 'ILVOBO' Bobo	Bobo Hardy Hydrangea	x	x	x	x	x	x	x	x	x	x	x								
Hydrangea paniculata 'Limelight'	Limelight Hydrangea	x	x	x	x	x	x	x	x	x	x	x								
Hydrangea quercifolia 'Pee Wee'	Pee Wee Oakleaf Hydrangea			x	x	x	x	x	x	x	x	x	x	x						
Hydrangea quercifolia 'Snowflake'	Snowflake Oakleaf Hydrangea			x	x	x	x	x	x	x	x	x	x	x						
Hypericum calycinum	St. John's Wort				x	x	x	x	x	x	x	x	x	x						
Hypericum frondosum 'Sunburst'	Sunburst St. John's Wort				x	x	x	x	x	x	x	x								
Hyssopus officinalis 'Albus'	White Hyssop			x	x	x	x	x	x	x	x	x	x	x						
Hyssopus officinalis 'Roseus'	Pink Hyssop			x	x	x	x	x	x	x	x	x	x	x						
Ilex x meserveae 'MonNieves' Scallywag	Scallywag Holly			x	x	x	x	x	x	x	x	x	x	x						
Ilex crenata 'Sky Pencil'	Sky Pencil Holly					x	x	x	x	x	x	x								
Jamesia americana	Waxflower	x	x	x	x	x	x	x	x	x	x	x								
Juniperus × pfitzeriana 'Sea Green'	Sea Green Juniper	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus chinensis 'Daub's Frosted'	Daub's Frosted Juniper		x	x	x	x	x	x	x	x	x	x	x	x						x

Plants		Zones													Best Management Practices (BMPs)					
Shrubs	Common Name	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b	Basins	Swales	Strips	Bioretention Cells/ Rain Gardens	Tree Box Filters	Green Roofs
Juniperus chinensis 'Kaizuka'	Kaizuka Juniper				x	x	x	x	x	x	x	x	x	x						x
Juniperus chinensis 'Spearmint'	Spearmint Juniper	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus communis	Common Juniper	x	x	x	x	x	x	x												x
Juniperus communis	Common Juniper	x	x	x	x	x	x	x												x
Juniperus communis 'Repanda'	Juniperus communis 'Repanda'	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus horizontalis 'Wiltonii'	Blue Rug Juniper	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus horizontalis 'Bar Harbor'	Bar Harbor Juniper	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus horizontalis 'Blue Chip'	Blue Chip Juniper	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus horizontalis 'Hughes'	Hughes Juniper	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus horizontalis 'Monber'	Icee Blue Juniper	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus osteosperma	Utah Juniper	x	x	x	x	x	x	x	x	x										x
Juniperus sabina 'Buffalo'	Buffalo Juniper	x	x	x	x	x	x	x	x	x	x	x								x
Juniperus sabina 'Skandia'	Skandia Juniper		x	x	x	x	x	x	x	x										x
Juniperus scopulorum	Rocky Mountain Juniper		x	x	x	x	x	x	x	x	x	x	x	x						x
Juniperus scopulorum 'Gray Gleam'	Gray Gleam Juniper		x	x	x	x	x	x	x	x										x
Juniperus scopulorum 'Skyrocket'	Skyrocket Juniper	x	x	x	x	x	x	x	x	x	x	x								x
Juniperus scopulorum 'Tabletop'	Tabletop Juniper	x	x	x	x	x	x	x	x	x										x
Juniperus x pfitzeriana 'Monsan'	Sea of Gold Juniper	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Kerria japonica 'Pleniflora'	Double-Flowering Japanese Kerria		x	x	x	x	x	x	x	x	x	x	x	x						
Kerria japonica 'Picta'	Japanese Variegated Kerria		x	x	x	x	x	x	x	x	x	x	x	x						
Kolkwitzia amabilis 'Maradco' Dream Catcher	Dream Catcher Beautybush		x	x	x	x	x	x	x	x	x	x								
Kolkwitzia amabilis 'Pink Cloud'	Pink Cloud Beautybush		x	x	x	x	x	x	x	x	x	x								
Lavandula angustifolia	English Lavendar				x	x	x	x	x	x	x	x								x
Lavandula angustifolia 'Granny's Bouquet'	Granny's Bouquet Lavender		x	x	x	x	x	x	x	x	x	x								x
Lavandula Angustifolia 'Hidecote'	Hidcote True Lavender				x	x	x	x	x	x	x	x								x
Lavandula angustifolia 'Lavance Purple'	Lavance Purple Lavender				x	x	x	x	x	x	x	x	x	x						x
Lavandula angustifolia 'Wee One'	Wee One dwarf English lavender				x	x	x	x	x	x	x	x	x	x						x
Lavandula angustifolia 'Munstead'	Munstead Lavender				x	x	x	x	x	x	x	x								x
Ligustrum x vicaryi	Vicary Golden Privet				x	x	x	x	x	x	x	x								
Lonicera involucrata	Twinberry Honeysuckle				x	x	x	x	x	x	x	x								
Lonicera korolkowii 'Floribunda'	BLUE VELVET® honeysuckle	x	x	x	x	x	x	x	x	x	x	x			x	x				
Lonicera maackii	Amur Honeysuckle	x	x	x	x	x	x	x	x	x	x	x			x	x				
Mahonia aquifolium 'Compacta'	Dwarf Oregon Grape		x	x	x	x	x	x	x	x	x	x	x	x						
Mahonia fremontii	Fremont Mahonia		x	x	x	x	x	x	x	x	x	x	x	x						
Mahonia haematocarpa	Red Berry Mahonia				x	x	x	x	x	x	x	x	x	x						
Mahonia repens	Creeping Mahonia, Oregon Grape				x	x	x	x	x	x	x	x								
Paxistima myrsinites	Mountain Lover	x	x	x	x	x	x	x												
Pentaphylloides floribunda	Shrubby Cinquefoil				x	x	x	x							x	x		x		
Philadelphus coronarius 'Aureus'	Golden Mock Orange				x	x	x	x	x	x	x	x	x	x						
Philadelphus lewisii 'Blizzard'	Blizzard Mock Orange	x	x	x	x	x	x	x	x	x	x	x						x		
Philadelphus lewisii 'Cheyenne'	Cheyenne Mock Orange	x	x	x	x	x	x	x	x	x	x	x						x		
Philadelphus lewisii 'PWY01S'	CHEYENNE® mock orange	x	x	x	x	x	x	x	x	x	x	x	x	x				x		
Philadelphus x virginalis 'Minnesota Snowflake'	Minnesota Snowflake Mock Orange		x	x	x	x	x	x	x	x	x									
Philadelphus microphyllus	Littleleaf Mock Orange				x	x	x	x	x	x	x	x	x	x						
Philadelphus 'Snow White Fantasy' First Editions Snow White	Snow White Mock Orange		x	x	x	x	x	x	x	x										
Physocarpus opulifolius 'Amber Jubilee'	Amber Jubilee Ninebark	x	x	x	x	x	x	x	x	x	x	x								x
Physocarpus opulifolius 'Dart's Gold'	Dart's Gold Ninebark	x	x	x	x	x	x	x	x	x										x
Physocarpus opulifolius 'Diabolo'	Diabolo Ninebark	x	x	x	x	x	x	x	x	x										x
Physocarpus opulifolius 'Nanus'	Dwarf Ninebark	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Physocarpus opulifolius 'Nugget'	Nugget Ninebark	x	x	x	x	x	x	x	x	x	x	x								x
Physocarpus opulifolius 'Seward'	Summer Wine Ninebark	x	x	x	x	x	x	x	x	x	x	x								x
Physocarpus opulifolius 'POIPD2'	Petite Plum Ninebark	x	x	x	x	x	x	x	x	x	x	x								x
Physocarpus opulifolius 'SMPOTW'	Tiny Wine Ninebark	x	x	x	x	x	x	x	x	x	x	x								x
Picea abies 'Nidiformis'	Bird's Nest Spruce	x	x	x	x	x	x	x	x	x	x									
Picea pungens 'Glauca Globosa'	Globe Colorado Spruce	x	x	x	x	x	x	x	x	x	x	x								
Picea pungens 'Glauca Procumbens'	Creeping Blue Spruce	x	x	x	x	x	x	x	x	x	x	x								
Picea pungens 'Montgomery'	Montgomery Blue Spruce	x	x	x	x	x	x	x	x	x										
Pinus mugo	Mugo Pine	x	x	x	x	x	x	x	x	x										
Pinus mugo 'Big Tuna'	Big Tuna Mugo Pine	x	x	x	x	x	x	x	x	x										
Pinus mugo 'Mops'	Mops Mugo Pine	x	x	x	x	x	x	x	x	x										
Pinus mugo 'Slowmound'	Slowmound Mugo Pine	x	x	x	x	x	x	x	x	x										
Pinus sylvestris 'Hillside Creeper'	Hillside Creeper Scots Pine	x	x	x	x	x	x	x	x	x	x	x								

Plants		Zones													Best Management Practices (BMPs)					
Shrubs	**Common Name**	**3b**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**	**7a**	**7b**	**8a**	**8b**	**9a**	**9b**	**Basins**	**Swales**	**Strips**	**Bioretention Cells/ Rain Gardens**	**Tree Box Filters**	**Green Roofs**
Potentilla fruticosa 'Goldfinger'	Goldfinger Shrubby Cinquefoil	x	x	x	x	x	x	x	x	x					x	x				x
Potentilla fruticosa 'Gold Drop'	Gold Drop Shrubby Cinquefoil	x	x	x	x	x	x	x	x	x					x					
Potentilla fruticosa 'McKay's White'	McKay's White Shrubby Cinquefoil	x	x	x	x	x	x	x	x	x					x					
Potentilla fruticosa 'Monsidh'	Frosty Shrubby Cinquefoil	x	x	x	x	x	x	x	x	x					x					
Prunus x cistena	Purple-Leaf Sand Cherry		x	x	x	x	x	x	x	x	x	x								
Prunus besseyi	Western Sand Cherry		x	x	x	x	x	x	x	x	x	x								
Prunus besseyi 'Pawnee Buttes'	Pawnee Buttes Western Sand Cherry		x	x	x	x	x	x	x	x	x	x								
Prunus besseyi 'P011S'	PAWNEE BUTTES® sand cherry	x	x	x	x	x	x	x	x	x	x	x								
Prunus glandulosa 'Sinensis'	Dwarf Flowering Almond				x	x	x	x	x	x	x	x								
Prunus virginiana	Chokecherry	x	x	x	x	x	x	x							x	x				x
Prunus x cistena	Purple-Leaf Sand Cherry	x	x	x	x	x	x	x	x	x	x	x								
Purshia mexicana	Cliffrose				x	x	x	x	x	x	x	x	x	x						
Purshia tridentata	Antelope Bitterbrush				x	x	x	x	x	x	x	x	x	x						
Pyracantha fortuneana 'Graberi'	Graber's Firethorn				x	x	x	x	x	x	x	x	x	x						
Ribes aureum	Golden Currant	x	x	x	x	x	x	x										x		
Ribes cereum	Wax Currant		x	x	x	x												x		
Ribes rubrum 'Red Lake'	Ribes rubrum 'Red Lake'	x	x	x	x	x	x	x	x	x										
Ribes uva-crispa 'Red Jacket'	Comanche gooseberry	x	x	x	x	x	x	x	x	x	x	x	x	x						
Rhamnus frangula 'Columnaris'	Tallhedge Buckthorn	x	x	x	x	x	x	x	x	x	x									
Rhamnus frangula 'Ron Williams'	Fine Line Buckthorn	x	x	x	x	x	x	x	x	x	x									
Rhamnus smithii	Smith's buckthorn		x	x	x	x	x	x	x	x	x	x								
Rhus aromatica 'Gro-Low'	Grow-Low Sumac	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				x
Rhus glabra	Smooth Sumac	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Rhus glabra 'Laciniata'	Cutleaf Smooth Sumac	x																		
Rhus trilobata	Three-Leaf Sumac		x	x	x	x	x	x	x	x	x	x			x	x		x		x
Rhus trilobata 'Autumn Amber'	Autumn Amber Sumac		x	x	x	x	x	x	x	x	x	x						x		x
Rhus typhina 'Bailtiger'	Tiger Eyes Sumac		x	x	x	x	x	x	x	x	x	x			x	x				
Ribes alpinum 'Green Mound'	Green Mound Alpine Currant	x	x	x	x	x	x	x	x	x										
Ribes aureum	Golden Currant	x	x	x	x	x	x	x	x	x					x	x				x
Riber cereum	Wax Currant		x	x	x	x														
Ribes hirtellum 'Pixwell'	Pixwell Gooseberry		x	x	x	x	x	x												
Rosa 'F.J. Grootendorst'	F.J. Grootendorst Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Rosa 'Meidomonac'	Bonica Shrub Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Rosa 'Meikrotal' Scarlet Meidiland	Scarlet Meidiland Shrub Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Rosa x 'Radrazz'	Radrazz Knock Out Rose				x	x	x	x	x	x	x	x	x	x						
Rosa 'Meigekanu' La Sevillana	La Sévillana Shrub Rose				x	x	x	x	x	x	x	x	x	x						
Rosa x harisonii 'Harison's Yellow'	Harison's Yellow Rose	x	x	x	x	x	x	x	x	x	x	x	x	x						
Rosa 'Thérèse Bugnet'	Thérèse Bugnet Rose	x	x	x	x	x	x	x	x	x	x	x	x	x						
Rosa 'Wekboroco' Rockin' Robin	Rockin' Robin Shrub Rose		x	x	x	x	x	x	x	x	x	x								
Rosa floribunda 'WEKsmopur'	Ebb Tide Floribunda Rose					x	x	x	x	x	x	x	x	x						
Rosa foetida	Austrian Yellow Rose	x	x	x	x	x	x	x	x	x	x	x								
Rosa foetida bicolor	Austrian Copper Rose		x	x	x	x	x	x	x	x	x	x	x	x						
Rosa glauca, R. rubrifolia	Redleaf rose	x	x	x	x	x	x	x	x	x	x	x	x	x						
Rosa 'Ruby Voodoo'	Ruby Voodoo rose		x	x	x	x	x	x	x	x	x	x	x	x						
Rosa x 'Tanamabar' Caramba	Caramba Shrub Rose				x	x	x	x	x	x	x	x	x	x						
Rosa floribunda 'WEKcobeju'	Cinco de Mayo Shrub Rose						x	x	x	x	x	x	x	x						
Rosa 'Radtkopink' Pink Double Knock Out	Pink Double Knock Out Rose																			
Rosa woodsii	Woods' Rose		x	x	x	x	x	x	x	x	x	x	x	x	x	x				
Rosmarinus officinalis 'Arp'	Arp Rosemary						x	x	x	x	x	x	x	x						
Rubus idaeus 'NR7' Raspberry Shortcake	Raspberry Shortcake Dwarf Thornless Raspberry		x	x	x	x	x	x	x	x	x	x	x	x						
Salix bebbiana	Bebb's Willow		x	x	x	x									x	x		x		
Salix boothii	Bebb's Willow		x	x	x	x									x	x		x		
Salvia dorrii	Desert Purple Sage				x	x	x	x	x	x	x	x	x	x						
Salix drummondiana	Drummond Willow	x	x	x											x	x		x		
Salix exigua	Coyote Willow	x	x	x											x	x		x		
Salix geyeriana	Geyer Willow	x	x	x											x	x		x		
Salix lemmonii	Lemmon Willow	x	x	x											x	x		x		
Salix lutea	Yellow Willow	x	x	x											x	x		x		
Salix planifolia	Planeleaf Willow	x	x	x											x	x		x		
Salix scouleriana	Scouler Willow		x	x	x	x	x	x							x	x		x		
Sambucus nigra 'EIFFEL 1'	Black Tower Elderberry		x	x	x	x	x	x	x	x	x	x						x	x	
Sambucus nigra 'Eva'	Black Lace Elderberry		x	x	x	x	x	x	x	x								x	x	

Plants		Zones													Best Management Practices (BMPs)					
Shrubs	Common Name	3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b	Basins	Swales	Strips	Bioretention Cells/ Rain Gardens	Tree Box Filters	Green Roofs
Sambucus nigra 'Gerda' x	Black Beauty Elderberry		x	x	x	x	x	x	x	x	x	x						x	x	
Sambucus nigra f. laciniata	Cutleaf Elderberry		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Shepherdia argentea	Silver Buffaloberry	x	x	x	x	x	x	x							x	x				x
Spiraea x bumalda 'Anthony Waterer'	Anthony Waterer Spirea		x	x	x	x	x	x	x	x	x	x								
Spiraea x bumalda 'Froebelii'	Froebelii Spirea		x	x	x	x	x	x	x	x	x	x	x	x						
Sibiraea laevigata	Siberian spirea		x	x	x	x	x	x	x	x	x	x								
Sorbaria sorbifolia	False Spirea	x	x	x	x	x	x	x	x	x	x	x								
Spiraea x billardii 'Triumphans'	Triumphans Spirea		x	x	x	x	x	x	x	x	x	x								
Spiraea x cinerea 'Grefsheim'	First Snow Spirea		x	x	x	x	x	x	x	x	x	x	x	x						
Spiraea betulifolia 'Tor'	Tor Birchleaf Spirea		x	x	x	x	x	x	x	x	x	x								
Spirea x vanhouttei	Vanhoutte Spirea	x	x	x	x	x	x	x	x	x	x	x			x	x				
Spiaea joponica 'Anthony Waterer'	Anthony Waterer Spirea		x	x	x	x	x	x	x	x	x	x								
Spiraea japoinica 'Gold Mound'	God Mound Spirea		x	x	x	x	x	x	x	x	x	x								
Spiraea japonica	Spirea		x	x	x	x	x	x	x	x	x	x	x	x						
Spiraea joponica Coccinea	Coccinea spirea		x	x	x	x	x	x	x	x	x	x	x	x						
Spirea japonica 'Tracy' DOUBLE PLAY BIG BANG	Double Play Big Bang Spirea		x	x	x	x	x	x	x	x	x	x	x	x						
Spiraea japonica 'Firelight'	Firelight Spirea		x	x	x	x	x	x	x	x	x	x								
Spiraea japonica 'Galen'	Double Play Artisan Spirea		x	x	x	x	x	x	x	x	x	x	x	x						
Spiraea japonica 'Gold Mound'	Gold Mound Spirea		x	x	x	x	x	x	x	x	x	x								
Spiraea japonica 'Neon Flash'	Neon Flash Spirea		x	x	x	x	x	x	x	x	x	x								
Spiraea japonica 'Yan'	Double Play Gold Spiraea		x	x	x	x	x	x	x	x	x	x	x	x						
Spiraea japonica 'walbuma' MAGIC CARPET	Magic Carpet Spirea		x	x	x	x	x	x	x	x	x	x	x	x						
Spirea media 'SMSMBK' Double Play Blue Kazoo	Double Play Blue Kazoo Spirea		x	x	x	x	x	x	x	x	x	x	x	x						
Spiraea nipponica 'Snowmound'	Snowmound Spirea	x	x	x	x	x	x	x	x	x	x	x								
Spiraea thunbergii 'Ogon'	Ogon Spirea		x	x	x	x	x	x	x	x	x	x								
Spiraea x cinerea 'Grefsheim'	First Snow Spirea		x	x	x	x	x	x	x	x	x	x	x	x						
Spiraea x vanhouttei	Vanhoutte Spirea		x	x	x	x	x	x	x	x	x	x								
Symphoricarpos albus	Snowberry	x	x	x	x	x	x	x	x	x										
Symphoricarpos x chenaultii 'Hancock'	Hancock Coralberry		x	x	x	x	x	x	x	x										
Syringa hyacinthiflora 'Pocahontas'	Pocahontas Lilac	x	x	x	x	x	x	x	x											
Syringa meyeri 'Palibin'	Dwarf Korean Lilac	x	x	x	x	x	x	x	x											
Syringa pubescens ssp. patula 'Miss Kim'	Miss Kim Lilac	x	x	x	x	x	x	x	x	x	x	x								
Syringa vulgaris 'Charles Joly'	Charles Joly Lilac	x	x	x	x	x	x	x	x	x										
Syringa vulgaris 'Président Grévy'	President Grevy Lilac	x	x	x	x	x	x	x	x	x					x	x				x
Syringa vulgaris 'Sensation'	Sensation Lilac	x	x	x	x	x	x	x	x	x										
Syringa x hyacinthiflora 'Mount Baker'	Mount Baker Lilac	x	x	x	x	x	x	x	x	x										
Syringa x hyacinthiflora 'Mount Baker'	Mount Baker Lilac	x	x	x	x	x	x	x	x											
Syringa x josiflexa 'James MacFarlane'	James MacFarlane Lilac	x	x	x	x	x	x	x	x											
Syringa x 'Penda' BLOOMERANG	Bloomerang Purple Lilac	x	x	x	x	x	x	x	x	x										
Taxus x media 'Dark Green Spreader'	Dark Green Spreader Yew		x	x	x	x	x	x	x	x										
Taxus cuspidata 'Monloo' Emerald Spreader	Emerald Spreader Japanese Yew		x	x	x	x	x	x	x	x										
Taxus x media 'Dark Green Spreader'	Dark Green Spreader Yew		x	x	x	x	x	x	x	x										
Taxus x media 'Huber's Tawny Gold'	Huber's Tawny Gold spreading Yew		x	x	x	x	x	x	x	x										
Veronica 'Sunny Border Blue'	Sunny Border Blue Speedwell	x	x	x	x	x	x	x	x	x	x	x	x							
Viburnum x burkwoodii	Burkwood Viburnum				x	x	x	x	x	x	x	x	x							
Viburnum x rhytidophylloides 'Alleghany'	Alleghany Viburnum			x	x	x	x	x	x	x	x	x								
Viburnum carlesii	Koreanspice Viburnum		x	x	x	x	x	x	x	x										
Viburnum burejaeticum 'P017S'	Mini Man™ dwarf Manchurian viburnum	x	x	x	x	x	x	x	x	x										
Viburnum dentatum 'Ralfph Senior' Autumn Jazz	Autum Jazz Viburnum	x	x	x	x	x	x	x	x	x	x	x								
Viburnum lentago	Nannyberry	x	x	x	x	x	x	x	x	x	x	x	x		x					
Viburnum opulus var. americanum	American Cranberrybush, Vibrnum	x	x	x	x	x	x	x	x	x										
Viburnum opulus var. americanum 'Bailey Compact'	Bailey Compact American Cranberrybush	x	x	x	x	x	x	x	x											
Viburnum plicatum f. tomentosum 'Shasta'	Doublefile Viburnum				x	x	x	x	x	x	x	x								
Viburnum x rhytidophylloides 'Alleghany'	Alleghany Viburnum				x	x	x	x	x	x	x	x								
Weigela 'Slingco 1'	Crimson Kisses Weigela		x	x	x	x	x	x	x	x	x	x	x	x						

Plants		Zones													Best Management Practices (BMPs)					
Grasses	**Common Name**	**3b**	**4a**	**4b**	**5a**	**5b**	**6a**	**6b**	**7a**	**7b**	**8a**	**8b**	**9a**	**9b**	**Basins**	**Swales**	**Strips**	**Bioretention Cells/ Rain Gardens**	**Tree Box Filters**	**Green Roofs**
Agropyron spp.	BioNative Wheatgrass Mix		x	x	x	x	x	x	x	x					x	x	x	x		
Bouteloua gracilis	Blue Grama	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Bouteloua gracilis 'Blonde Ambition'PP 22,048	Blonde Ambition grama grass		x	x	x	x	x	x	x	x	x	x	x	x						x
Buchloë dactyloides 'Legacy'	Legacy Buffalo Grass	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Calamagrostis xacutiflora 'Eldorado'	Eldorado Feather Reed Grass		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Calamagrostis x acutiflora 'Karl Foerster'	Karl Foerster Feather Reed Grass		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Calamagrostis brachytricha	Korean feather reed grass		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Calamagrostis x acutiflora 'Overdam'	Overdam Feather Reed Grass				x	x	x	x	x	x	x	x	x	x				x	x	
Eriogonum caespitosum	Mat Buckwheat		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Festuca spp.	BioMeadow Fine Fescue Mix		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
Festuca arundinacea	Dwarf Tall Fescue				x	x	x	x	x	x	x	x			x	x		x	x	x
Festuca arundinacea 'Bolero'	BioTurf Dwarf Fescue Mix				x	x	x	x	x	x	x	x			x	x		x	x	x
Festuca arundinacea 'Bonsai'	Bonsai Dwarf Tall Fescue				x	x	x	x	x	x	x	x			x	x		x	x	x
Festuca glauca	Blue Fescue		x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x
Festuca glauca 'Boulder Blue'	Border Blue Fescue														x	x		x	x	x
Festuca glauca 'Elijah Blue'	Elijah Blue Fescue		x	x	x	x	x	x	x	x	x	x			x	x		x	x	x
Helictotrichon sempervirens	Blue Oat Grass		x	x	x	x	x	x	x	x	x	x	x	x						x
Imperata cylindrica 'Rubra'	Japanese Blood Grass				x	x	x	x	x	x	x	x	x	x				x	x	
Miscanthus x giganteus	Giant Chinese Silver Grass		x	x	x	x	x	x	x	x	x	x	x	x						x
Miscanthus 'Purpurascens'	Flame Grass		x	x	x	x	x	x	x	x	x	x	x	x						x
Miscanthus sacchariflorus	Silver Banner Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Adagio'	Adagio Maiden Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Cabaret'	Cabaret Japanese Silver Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Gold Bar'	Gold Bar Maiden Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Gracillimus'	Gracillimus Maiden Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Graziella'	Graziella Maiden Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Silberfeder' Silver Feather	Silver Feather Maiden Grass		x	x	x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Strictus'	Porcupine Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'varigatus'	Variegated Maiden Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Pünktchen' Little Dot	Little Dot Maiden Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Morning Light'	Morning Light Maiden Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Yaku Jima'	Yaku Jima Maiden Grass				x	x	x	x	x	x	x	x	x	x						x
Miscanthus sinensis 'Zebrinus'	Zebra Grass				x	x	x	x	x	x	x	x	x	x						x
Panicum virgatum 'Dallas Blues'	Dallas Blues Switch Grass				x	x	x	x	x	x	x	x	x	x				x	x	
Panicum virgatum 'Cloud Nine'	Cloud Nine Switch Grass				x	x	x	x	x	x	x	x	x	x				x	x	
Panicum virgatum 'Heavy Metal'	Heavy Metal Switch Grass				x	x	x	x	x	x	x	x	x	x				x	x	
Panicum virgatum 'Prairie Sky'	Prairie Sky Switch Grass		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Panicum virgatum 'Rotstrahlbusch'	Red Switch Grass				x	x	x	x	x	x	x	x	x	x				x	x	
Panicum virgatum 'Shenandoah'	Shenandoah Switch Grass				x	x	x	x	x	x	x	x	x	x				x	x	
Panicum virgatum 'Strictum'	Upright Switch Grass		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Pennisetum alopecuroides 'Little Bunny'	Little Bunny Dwarf Fountain Grass						x	x	x	x	x	x	x	x				x	x	
Poa pratensis	BioBlue Kentucky Bluegrass Mix				x	x	x	x	x	x	x	x			x	x	x	x		x
Schizachyrium scoparium	Little Bluestem				x	x	x	x	x	x	x	x	x	x				x	x	
Schizachyrium scoparium 'Blaze'	Blaze Little Bluestem		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Schizachyrium scoparium 'Prairie Blues'	Prairie Blues Little Bluestem		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Schizachyrium scoparium 'Standing Ovation' PP25,202	Standing Ovation little bluestem	x	x	x	x	x	x	x	x	x	x	x						x	x	
Spartina pectinata	Prairie cordgrass		x	x	x	x	x	x	x	x	x	x			x	x	x	x	x	
Sporobolus airoides	Alkali Sacaton		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Sporobolus wrightii	Giant sacaton				x	x	x	x	x	x	x	x						x	x	
Sporobolus wrightii 'Windbreaker'	Windbreaker Giant Sacaton				x	x	x	x	x	x	x	x	x	x				x	x	

Plants		Zones													Best Management Practices (BMPs)					
Groundcovers		3b	4a	4b	5a	5b	6a	6b	7a	7b	8a	8b	9a	9b	Basins	Swales	Strips	Bioretention Cells/ Rain Gardens	Tree Box Filters	Green Roofs
Juniperus horizontalis 'Bar Harbor'	Bar Harbor Juniper	x	x	x	x	x	x	x	x	x	x	x								x
Juniperus horizontalis 'Hughes'	Hughes Juniper	x	x	x		x	x	x	x	x	x	x	x	x						x
Juniperus sabina 'Buffalo'	Buffalo Juniper	x	x	x	x	x	x	x	x	x	x	x								x
Juniperus sabina 'Skandia'	Skandia Juniper		x	x	x	x	x	x	x	x										x
Nepeta racemosa 'Walker's Low'	Walker's Low Catmint		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Nepeta x faassenii 'Select Blue'	Select Blue Catmint		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Nepeta 'Psfike'	Little Trudy Catmint		x	x	x	x	x	x	x	x	x	x	x	x				x	x	
Nepeta sibirica 'Souvenir d' André Chaudron'	Souvenir d Andre Chaudron Catmint	x	x	x	x	x	x	x	x	x	x	x	x	x				x	x	x
Veronica liwanensis	Turkish veronica	x	x	x	x	x	x	x	x	x	x	x	x	x						x
Veronica oltensis	Thyme-leaf Speedwell		x	x	x	x	x	x	x	x	x	x	x	x						x

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APPENDIX G

STORM DRAIN DESIGN STANDARDS COMMENTS

SECTION 6: STORM DRAIN

1. DRAINAGE PLAN:

1. All new developments shall prepare and submit to the City Engineer for review and approval a drainage report that includes design drawings and appendices that address the following items:

   a. All system installation and designThe design of storm drain facilities must conform to Payson City's current Storm Water Master Plan and the City's current design standards.

   b. Storm drain facilities shall be designed and constructed such that post-development conditions mimic predevelopment conditions. This means that: a developing site must allow paths of historic runoff to be maintained across the site; that in most areas, storm water runoff from new impervious surfaces shall be retained onsite; and storm water runoff that from new development does not adversely impact downstream properties or existing storm water management facilities. Surface drainage shall be designed as such that all drainage is addressed within own project boundaries and not adversely affect other properties.

   c. Provide runoff calculations for pre-project and post-project development conditions. Identify Best Management Practices (BMPs) that will be implemented to limit post-development runoff to pre-development levels.

   b.d. If the existing ground cover will be significantly impacted during the development process, perform calculations and design for temporary BMPs for temporary controls to manage onsite runoff until site development and the associated storm water management facilities are constructed.

   c.e. Structural improvements and infrastructure shall be designed such that they shall be protectected from existing or future flood hazards associated with existing natural channel, drainage ways, and open channel irrigation facilities. Provide protection to the project from natural drainage ways such as existing drainage irrigation.

   d.f. Identify all existing storm drain and irrigation features within and adjacent to the project boundaries.

   e.g. Projects within a delineated FEMA special flood hazard zonewetlands or in areas with a shallowhigh groundwater table zone, must meet and address those conditions as part of the project including, but not limited to the following:

      i. Provide base floor elevations of buildingsminimal building elevations based on maximum groundwater table elevation provided by a

Formatted: Indent: Left: 0.5", No bullets or numbering professional geologist or geotechnical engineer using field measurements from a piezometer and other data as a referencedepth elevation.

ii. Provide the high groundwater table elevation measured during spring season.Meet requirements associated with the National Flood Insurance Program.

iii. Provide maintenance access along the banks of natural streams.

ii.iv. Where needed, provide channel stabilization measures to mitigate hazards associated with the lateral erosion and migration of natural stream channels.

f.h. Identify onsite and downstream public and private drainage systems that will be impacted by the development. Identify the characteristics of those systems and their capacities.

g.i. Provide overall pre-development and post-development pervious and impervious surface area measurements.

2. HYDRAULIC DESIGN CRITERIA:

a. The design of a storm drainage system should have as its objective the design of a balance between the maximum allowable discharge rate and downstream receiving system's capacity.

b. All drainage studies shall use rainfall data published NOAA Atlas 14 by the National Oceanic and Atmospheric Administration (NOAA).

c. The NOAA Precipitation Frequency Data Server is located at the following link: http://hdsc.nws.noaa.gov/hdsc/pfds/sa/ut_pfds.html

Duration	Frequency (inches/hour)					
	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
5 min	1.97	2.72	3.38	4.42	5.35	6.42
10 min	1.50	2.08	2.58	3.36	4.07	4.89
15 min	1.24	1.71	2.13	2.78	3.36	4.04
30 min	0.83	1.15	1.43	1.87	2.27	2.72
60 min	0.52	0.71	0.89	1.16	1.40	1.68
120 min	0.32	0.42	0.51	0.66	0.79	0.94
3 hours	0.24	0.31	0.37	0.47	0.55	0.65
6 hours	0.16	0.19	0.22	0.27	0.31	0.35
12 hours	0.10	0.12	0.14	0.16	0.18	0.20
24 hours	0.06	0.08	0.09	0.10	0.11	0.12

Commented [CB1]: This table needs to be identified as intensity. Use name from Atlas 14

Duration	Frequency (inches)					
	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year
5 min	0.16	0.23	0.28	0.37	0.45	0.54
10 min	0.25	0.35	0.43	0.56	0.68	0.82
15 min	0.31	0.43	0.53	0.70	0.84	1.01
30 min	0.42	0.58	0.72	0.94	1.14	1.36
60 min	0.52	0.71	0.89	1.16	1.40	1.68
120 min	0.64	0.84	1.02	1.31	1.57	1.87
3 hours	0.73	0.93	1.11	1.40	1.64	1.94
6 hours	0.94	1.15	1.34	1.60	1.84	2.11
12 hours	1.20	1.44	1.66	1.96	2.18	2.44
24 hours	1.51	1.80	2.04	2.38	2.64	2.88

Commented [CB2]: This table should reference depth-duration-frequency as it does in Atlas 14

d. Piped systems are to be designed using a ~~twenty five (25) year, twenty four (24) hour storm event~~10-year, 3-hour storm event as defined in the City's current Storm Drain Master Plan (or include in this document).

e. Retention or detention basins are to be designed using a one hundred (100) year, twenty four (24) hour storm event.

f. The storm water drainage system shall be separated and independent of the sanitary sewer system.

g. Storm drainage conveyance system facilities shall be designed using the Rational Method or other methods approved by the City Engineer. Hillside developments must also use the TR-55 method to analyze the drainage channels from above the development.

h. A copy of the storm drainage calculations shall be submitted with the drainage report and design drawings.~~along with the construction plans~~.

Commented [CB3]: For the design of pipelines, if a dynamic model is used, it is recommended that the Farmer-Fletcher 3-hour nested storm be used. The hyetograph for that storm should also be included in the standards…

Commented [CB4]: I recommend that storm drain sumps be added to this section. Add the treatment requirement and the design procedures required for sumps (require field infiltration tests, etc. and reference the City's standard detail for the sump design.

Commented [CB5]: Should defined design criteria….is this volume? What about freeboard, spillways, etc. What about considering the capacity of the conveyance system to route runoff to the detention/retention facility? Reference criteria below.

Commented [CB6]: I also recommend using software that can develop and route hydrographs when evaluating detention/retention facilities. Your standards should also include a design storm hyetograph, or precip distribution for design of conveyance facilities.

i. The ~~drainage calculations~~design drawings storm drain pipelines should include the Hydraulic Grade Line (HGL) elevations associated with the design.

j. Storm drain i~~I~~nlets shall be provided so that surface water is not carried across around any street intersections.

k. When calculations indicate that curb capacities are exceeded, catch basins shall be used to intercept flow.

~~k.~~l. Storm water from private development shall not be discharged onto downstream properties unless drainage or flood easements exist or have been acquired.

3. RETENTION OR DETENTION FACILITIES~~PONDS~~:

a. Retention or detention basins are to be designed using a one hundred (100) year, twenty four (24) hour storm event.

b. As part of the design considerations, a geotechnical study with a percolation rate is required to determine infiltration rates and the highest ground water table elevation.

c. Percolation test must show that the capability of draining the pond within twenty four (24) hours.

d. The lowest elevation of the bottom~~floor~~ of a detention or retention basin must be at least of one foot (1') above the highest anticipated elevation of the groundwater table.

e. In order to control erosion and sedimentation, the detention pond shall be landscaped with grass sod or rock on all the slopes and the bottom of the facility.

f. The maximum design depth for a storm drain detention basin shall be three feet (3') with an additional one foot (1') for free board to the top of the spillway.

g. The storm drain basin shall be designed with a minimum 5:1 (horizontal to vertical) slope.

h. Provide a minimum fifteen foot (15') wide maintenance access area to the hydraulic related features. Include a vehicle maintenance turnaround area.

4. STORM DRAIN PIPE~~ SIZE AND TYPE~~:

a. The storm drain pipe shall be located on the ~~North and West side of the street~~north side of east-west streets and on the west side of north-south streets.

b. The storm drain pipe shall be located four and one half feet (4.5') from the Top Back of Curb (TBC).

c. Unless otherwise approved by the City Engineer, t~~T~~he minimum ~~depth~~ cover shall be eighteen inches (18") measured from the bottom of the pavement~~road base~~ to the top of the pipe.

Commented [CB7]: Should probably add criteria here to retain onsite the 90th percentile storm AND encourage the use of LID practices wherever feasible. Reference the Utah LID manual.

Commented [CB8]: If maintaining detention/retention facilities on private property will remain the responsibility of private property owners, we suggest that the City develop a maintenance agreement the identifies owner responsibilities. MS4 Permits require periodic inspection by City staff.

Commented [CB9]: When sizing the volume of a retention basin, the City may allow some infiltration. This may be a conservative percentage of the infiltration rate measured in the field. USWAC is working on a table that you may want to consider.

Commented [CB10]: Where did this criteria come from. In some areas, this may allow Pharagmites and other types of plants to become established on the bottom of the facility.

Commented [CB11]: The City may want to specify where an emergency spillway can discharge if the 100-year design event is exceeded (i.e., road right-of-way, other?)

Commented [CB12]: Most have 3:1 slopes. 3:1 slopes can be mowed.

Commented [CB13]: In the roadway? This should be clarified.

d. The minimum vertical separation between a storm drain pipe and other utilities shall be twelve inches (12”).

e. The minimum public storm drain main pipeline diameter is fifteen inches (15”) ~~and twelve inches (12”) for laterals collecting runoff from one storm drain inlet~~.

f. All public storm drain lines within public right of ways shall be reinforced concrete pipe, unless otherwise approved by the City Engineer.

g. A storm drain manhole is required for accesses at all pipe transitions including changes in direction, elevation, slope, and pipe size.

h. ~~The minimum slope for a storm drain conveyance pipe is 0.40 percent.~~A storm drain pipe should be designed such that it does not surcharge during the 10-year design event.

Commented [CB14]: You may want to revise this slope base on pipe size and clarify that unless otherwise approved, a storm drain pipe should be designed such that it does not surcharge during the 10-year design event.

5. STORM DRAIN MANHOLES:

Commented [CB15]: Where applicable?

a. Storm drain manholes spacing shall not exceed four hundred feet (400’).

b. The construction of the storm drain manholes shall comply with the APWA Standard Plan 411.

c. Storm sewer thirty inches (30”) frame and cover shall conform to APWA Standard Plan 402.

d. Storm sewer cover collar for storm sewer manhole shall comply with APWA Standard Plan 413.

6. STORM DRAIN INLETS:

Commented [CB16]: Recommend adding criteria for sumps or injection wells. This should include pre-treatment, infiltration tests, overflow, field tests, water table restrictions, reference City’s standard detail, permitting, etc.

a. A minimum of twelve inches (12”) of separation from flow line of outlet pipe to the floor of the inlet box is required.

b. Inlet boxes shall be the drop back hood type of inlet box and comply with APWA Standard Plan 315.1 or 315.2.

c. Inlet boxes should be placed at a distance of no more than four hundred feet (400’) of street curb and gutter.

d. A double inlet type of boxes shall be installed at low points of vertical curves, downgrade cul-de-sacs or dead end streets and in areas with steep slopes.

e. The use of combination inlet type of structures is discouraged and allowed as approved by the City Engineer.

7. CULVERTS

Commented [CB17]: Define a culvert as a pipe that conveys runoff from an open channel under a road, canal, or railroad, etc.

a. The minimum culvert size is eighteen inches (18”) inches in diameter.

b. Trash racks shall be used where the City determines that there is a high risk of severe blockages.

Commented [CB18]: We recommend that you develop some criteria as to when a trash rack is required. If the culvert could be blocked, then the trash rack could be blocked and render the culvert useless. Consider safety and access by unauthorized people as a criteria

9. OPEN CHANNELS
    a. Shall be l~~L~~ocated within a dedicated right of way, drainage easement or equivalent.
    b. Convey a twenty-five (25) year twenty-four (24) hour storm event with a minimum freeboard of one foot (1’).
    c. Line with rock or other similar erosion control if velocities are expected to exceed two feet per second (2 fps).
    d. No side slopes steeper than 2H: 1V.

Commented [CB19]: Recommend defining what an open channel drainage facility is (historic creek, drainage channel or ephemeral wash; new drainage ditch, etc.)

Commented [CB20]: I recommend that the natural streams in Payson, those mapped by FEMA, be designed to convey the 100-year flood with freeboard. Provide a maintenance easement for access. Mitigate erosion hazards. Where possible, avoid construction of levees to confine water the the channel.

10. HEADWALLS
    a. For any culvert entrance or exit a headwall and concrete apron shall be required to control erosion.
    b. Staked rock with a concrete apron may be used for concrete pipe culverts.

Commented [CB21]: Recommend adding a definition of staked rock or calling out as riprap that is properly sized

11. EASEMENTS
    a. Minimum twenty-foot (20’) wide public utility easements (PUE) are required for all publicly owned and maintained storm sewer main lines located on private property.
    b. Storm drainage easements shall extend at least ten feet (10’) beyond dead end manholes.

12. PRIVATE LOT DRAIN CONNECTION:
    a. Lot drains shall use type SDR35 and the color white PVC for all piping.
    b. Lot drains shall be 4 inch diameter minimum.
    c. A back flow prevention device may be required on lot drain lines as determined by the City.

Commented [CB22]: Define what a lot drain is….a ground water drain or a drain pipe to convey runoff from roof downspouts or something else…..

13. WATER QUALITY:
    a. A pretreatment device is required prior to all new storm drain connections to a City storm drain facility, including pipes, streams or open channels, ~~onto a City system, into an underground~~ detention or retention basin systems, and~~which include~~ Class V Injection wells or sumps.
        i. Pretreatment device must meet manufacturer design requirements and the following criteria:
            1. Remove floatable contaminants.
            2. Filter sediments.
            3. Filter hydrocarbons.
    b. Pretreatment manhole shall comply with Payson City Standard Detail 343.

c. Submit a Storm Water Pollution Prevention Plan (SWPPP) for construction activity.

d. Provide a Storm Drainage System Maintenance Agreement for all BMP components of the proposed private drainage system.

   i. The party responsible for executing the maintenance agreement, i.e., homeowners or business association, property owner, etc.

   ii. Extent of the maintenance activities to be performed.

   iii. Frequency of the proposed recordkeeping and reporting of performed maintenance and inspection activities.

   iv. Provide easements to Payson City to access and inspect temporary and permanent storm water controls.

(Also, considering adding criteria for drainage design in roadway sags; avoiding down-sloping cul-de-sacs; how much pipe surcharge you will allow in conveyance pipes; referencing areas where shallow groundwater may limit the use of sumps or retention/detention basins; referencing protection zones where infiltration facilities should not be constructed; encouraging the use of injection wells, etc. And, if local retention/detention facilities are allowed, will they be temporary, or must they be dedicated to the City.

Erosion control and storm water management requirements on the hillsides should also be addressed in these standards.

We recommend that these design standards be updated with added detail to address our comments. That is not in our scope of work for the Master Plan.

You may consider developing a checklist for both residential and non-residential development that identifies items that should be included in the drainage report submittal. That may make your life easier.

This document should also be modified to include a reference to requiring LID practices, wherever possible. It should describe the process that should be followed to determine if LID is feasible, the documentation process, etc. Reference the Utah LID manual. Maybe the City wants to identify some LID practices that are pre-approved in some areas if they are different that sumps (injection wells) or retention basins.

Below are some recommendations for the design of storm drain facilities (some may be covered above). Detail needs to be added to some of these.

RECOMMENDED DESIGN CRITERIA FOR STORM DRAIN FACILITIES

The following general recommendations are given for future storm drain facilities:

Storm Drain Inlets and Pipes

1. Storm drain catch basins should be sufficient in number and size to collect runoff from a 10-year, 3-hour storm event, based on projected full build-out conditions. The maximum interval between storm drain inlets on new storm drain pipe construction should be 400 feet.
2. Storm drain pipes and trunklines in urban areas should be designed to convey runoff from a 10-year, 3-hour design storm, using the Farmer-Fletcher precipitation distribution, unless that pipeline serves as the primary conveyance for a natural creek or drainage. All pipes that convey runoff from large, natural drainage basins should be sized to convey runoff from a 100-year, 24-hour design storm that utilizes the SCS Type 2 storm distribution.
3. Storm drain pipes should be designed with slopes that will provide flow velocities greater than or equal to 2 feet per second at the design discharge. The minimum diameter of new storm drain pipes should be 18 inches.
4. All new streets should be designed to convey runoff from a 100-year, 3-hour storm while keeping runoff within the street right-of-way.

Detention and Retention Facilities

1. All new regional storm water detention/retention basins should be designed to store runoff from a 100-year, 24-hour design storm based on ultimate projected development conditions. The computed storage volume should not consider infiltration losses.
2. All new storm water detention/retention basins should be designed to include an emergency spillway.
3. Where possible, design detention facilities as dual-use facilities that can serve as parks or open space when not being utilized as storm water management facilities.

4. Geotechnical percolation studies should be performed prior to design of facilities that involve infiltration.

Open Channel Facilities

1. Storm water should not be discharged into existing irrigation ditches.
2. Open channels should be designed to convey the appropriate design discharge while providing at least 2 feet of freeboard.
3. Major streams and culverts should be designed to safely convey the 100-year flood.
4. Maintenance easements should be acquired or maintained along all open channels.
5. City and County officials should begin preserving and acquiring needed drainage corridors for future drainage facilities.

Storm Drain Sumps

1. Payson City's "Pretreatment Manhole and Sump Detail Inlet/Outlet" standard plan number 343 should be followed when designing a storm drain sump in the City. This standard plan should be referenced in the design specifications and/or should be shown in the project detail section of the drawing set.
2. Do not allow storm water sumps or injection wells to be installed within the 250-day well protection zone (Zone 2) for culinary water facilities or future culinary water facilities. Allowing storm water to discharge into protection zones has the potential to contaminate culinary water.
3. Geotechnical percolation studies should be performed prior to design of facilities that involve infiltration. Infiltration rates and groundwater levels should be determined as part of the design process.