Flood Insurance Study Hydraulic Analysis

for

Glenrose and Central-Park Basins

City of Spokane Valley, Washington

Draft

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Prepared For:

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Spokane County, Washington

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EXECUTIVE SUMMARY

A detailed hydraulic analysis of the Glenrose and Central Park (G-CP) Channels in the City of Spokane Valley (City) and Spokane County (County) was conducted. The purpose of the analysis was to establish flood inundation limits for the 10% (10-year) Annual Exceedance Probability (AEP) event up to the 0.2% (500-year) AEP event. A floodway analysis was conducted only along the Glenrose Channel within the County (upstream) and the City (downstream) for the 1% (100-year) AEP event. Peak inflows and "envelopes" containing the range of inflow hydrographs were developed from an earlier hydrologic study of the entire G-CP watersheds using HSPF. Stormflows from both the Glenrose and Central Park basins converge at the intersection of 8th Avenue and Carnahan Road. Due to the storage capacity of both the gravel pit south of 8th and the topographic bowl north of 8th at this intersection, flood flows do not overtop Carnahan and so do not continue westward into the City of Spokane.

Aside from identifying floodplain limits, the study also identified several areas of flooding with the potential to be reduced or eliminated. The areas included inflows to the southern part of the Taylor Cottages development using a culvert under E. 15th Avenue, inflows to the northern part of the Taylor Cottages development crossing S. Park Road in the vicinity of E. 13th Avenue, and flooding to the north of E. 8th Avenue from higher ground in the area of S. Fancher Road and S. Eastern Road. Mitigation might include terrain modification, additional dry wells and/or local flood storage.

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1 Introduction

In the south east and southwest corners of the City of Spokane Valley (City) and adjacent unincorporated Spokane County (County), Washington, stormwater from the Glenrose and Central Park (G-CP) watersheds enters and combines and then continues westward. A vicinity map of the watersheds is shown in Figure 1.

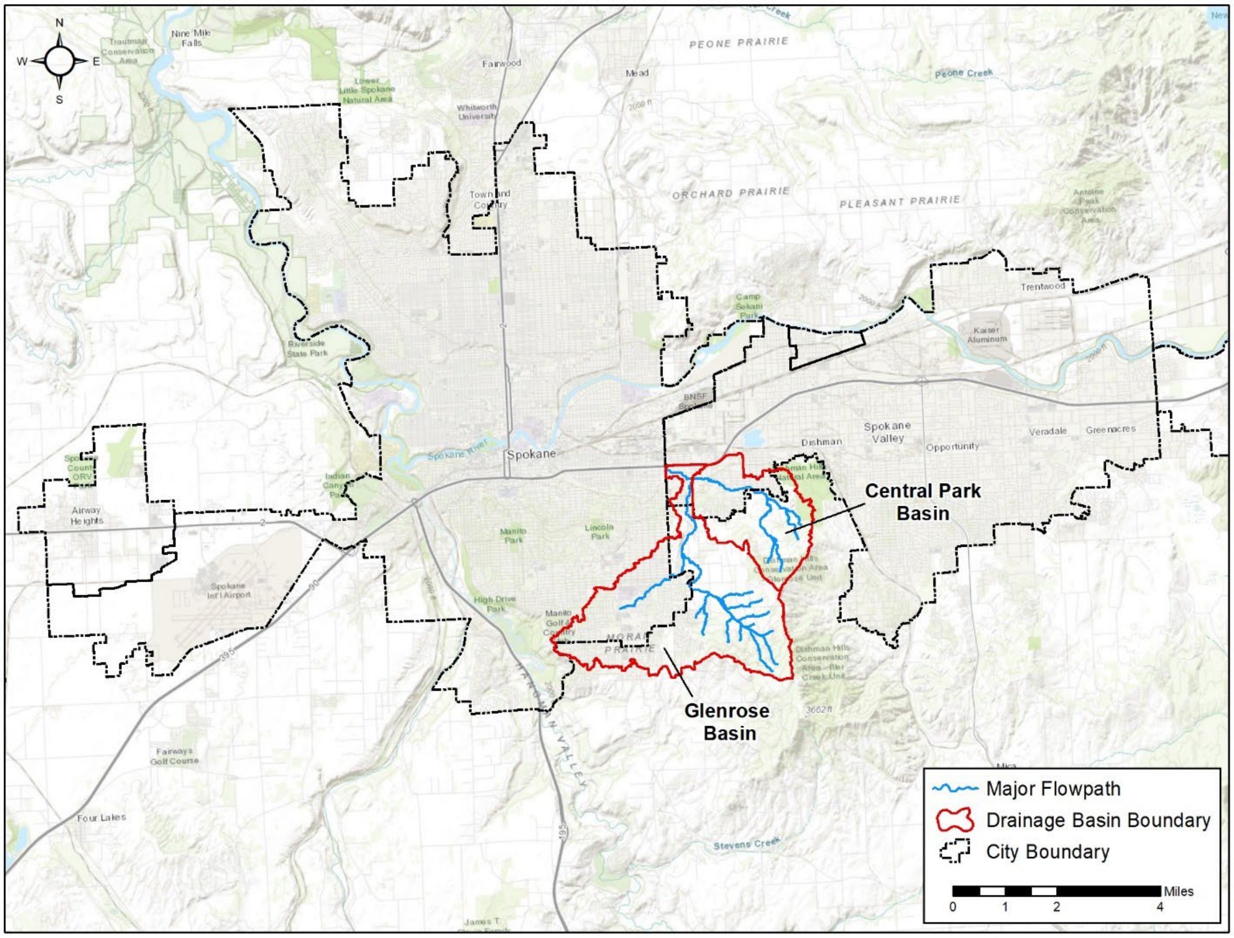

Figure 1: Vicinity Map

Currently, the area surrounding the main channels of the G-CP watersheds within Spokane Valley is in the Federal Emergency Management Agency (FEMA) Special Flood Hazard Areas (SFHAs) Zone A (1% Annual Exceedance Probability [AEP] flood hazard area also referred to as 100-year flood hazard area) or Zone X (0.2% AEP or 500-year flood hazard area) as published in the effective FEMA Flood Insurance Study (FIS) (FEMA, 2010). No detailed hydrologic or hydraulic analyses were performed for these watersheds and no base (1% AEP) flood elevations (BFEs) or depths were shown within these zones (Figure 2) on FEMA's Flood Insurance Rate Maps (FIRMs).

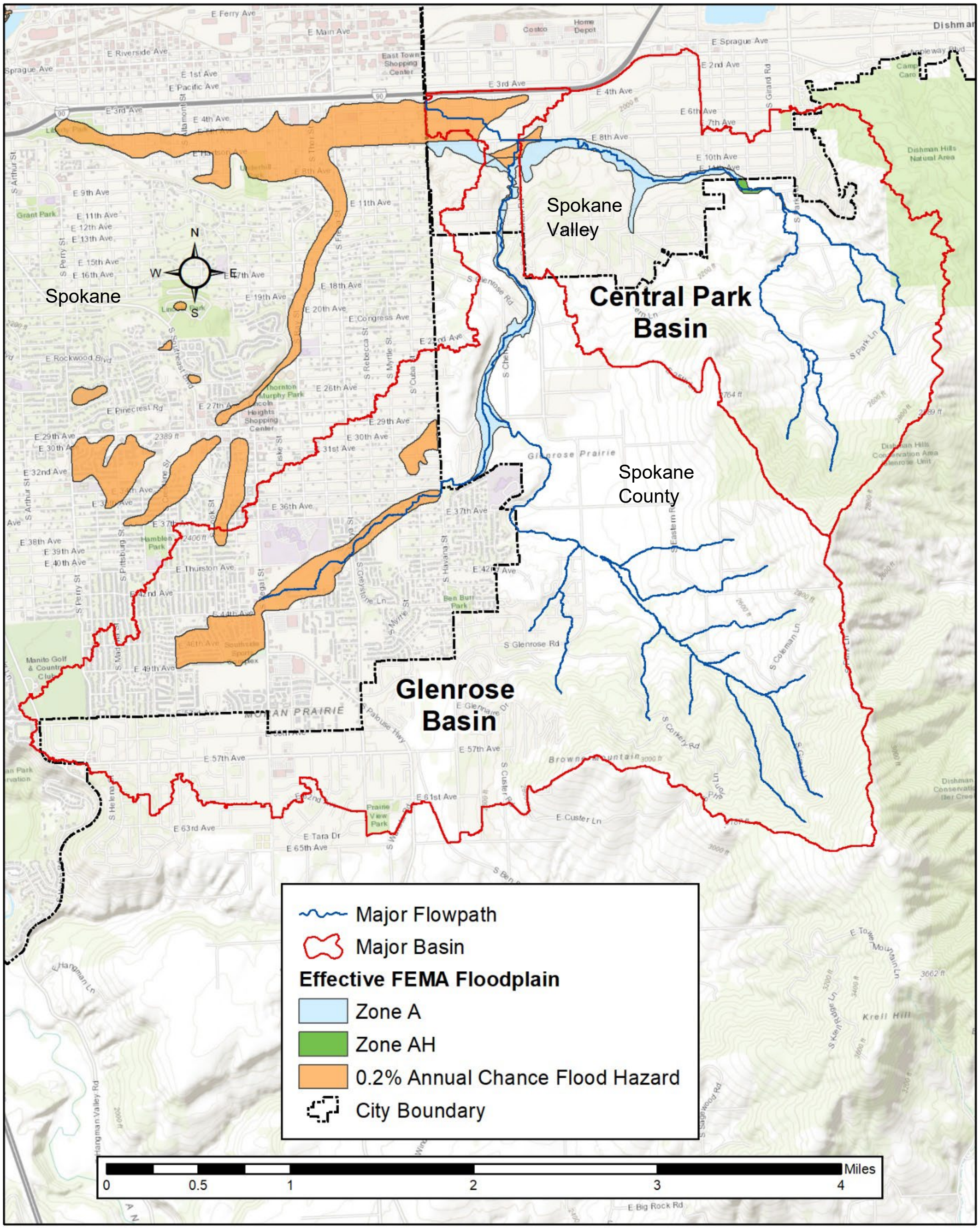

Figure 2: G-CP Basins with Major Flowpaths and Effective FEMA SFHAs

WEST Consultants, Inc. (WEST) conducted a study to update the 1% AEP flood (also referred to as the base flood or 100-year flood) and the 0.2% AEP flood (500-year) SFHAs in portions of the G-CP watersheds. A detailed hydrologic analysis was conducted using the Hydrological Simulation Program - FORTRAN (HSPF) (Bicknell et al. 1997) to develop flood frequency relationships for G-CP watersheds (WEST, 2023). The flood frequency data were then used in newly developed hydraulic models, using HEC-RAS v. 6.6 (HEC, 2024), to revise the SFHA delineations in the FIRMs.

The objective of this hydraulic study was to develop Special Flood Hazard Areas (SFHA), or flood inundation areas, and some floodways for the G-CP watershed within the City of Spokane Valley and Spokane County. Results from the HSPF hydrologic model were used to develop peak inflows into the hydraulic model area as well as to evaluate the maximum duration of these inflows to estimate maximum inflow volumes. This report presents the development of hydraulic models and their application to develop flood inundation areas and some local floodways.

1.1 Watershed Characteristics

The G-CP watersheds are adjacent basins located south of Interstate 90 and roughly centered along South Havana Street (Figure 3). The watersheds have a combined area of approximately 12.3 square miles. Each basin has areas with flat slopes where development is concentrated and areas of mountainous terrain in which there is only sparse development.

The **Glenrose basin** is approximately 9 square miles, with elevations ranging from 1,935 ft in gently sloped areas in the northwest, to 3,660 ft in mountainous areas in the southeast. The majority of the basin is within unincorporated Spokane County and the City of Spokane and only the most downstream portion is within the City of Spokane Valley. The area within the City of Spokane is mostly urbanized, while the area within the County is mostly rural. The stormwater in the drainage basin flows south to north, originating in the County and Spokane, and flows through the southeast and southwest corners of the City. While topography shows evidence of historic flows, it appears that most water is infiltrated into the ground prior to entering the City boundaries. In the City, groundwater flows occasionally appear to surface just southwest of 9th Ave and Carnahan Rd in a pond and overflow to the north into a ditch-system designed for local neighborhood stormwater flows. In the northern part of the basin and in spots within Spokane are areas of highly infiltrative, glacial flood-burst, outwash deposits.

The **Central Park basin** is approximately 3.3 square miles and covers areas within the City and the County. It primarily consists of mountainous areas (elevations up to 3,054 ft) in the southeast, and urbanized areas (approximate elevation of 1,940 ft) in the northwest portion of the basin. The headwaters of the basin are within the rural and undeveloped areas and the lower areas are primarily single-family residential. Stormwater in the County portion of the basin flows generally south to north, and then travels east to west through the City eventually joining the Glenrose channel at the gravel pit at 8th Ave and Carnahan Rd. In the northern part of the basin are areas of highly infiltrative, glacial flood-burst, outwash deposits.

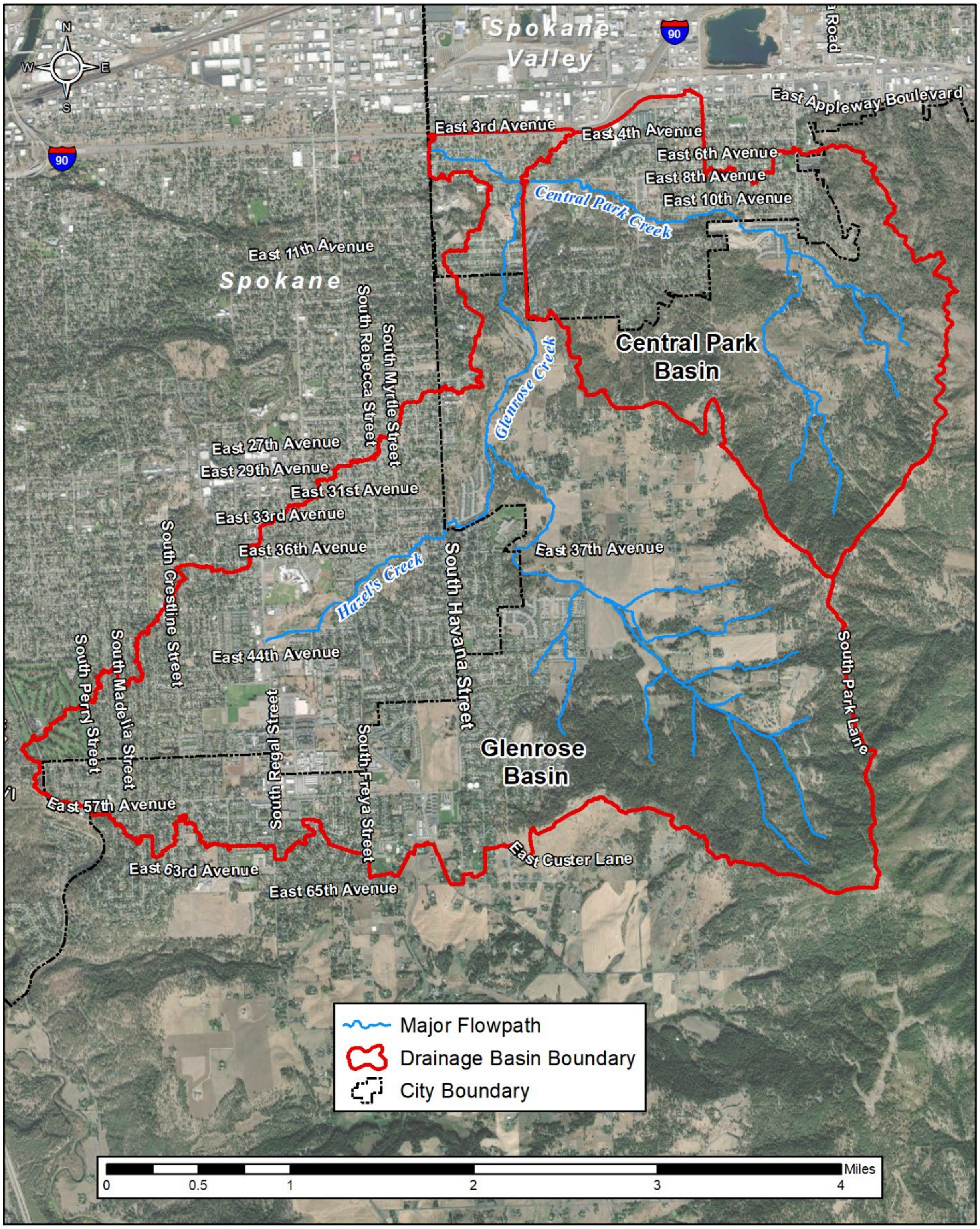

Figure 3: Watershed Map with Major Flowpaths

1.2 Background and Flooding Problems

1.2.1 Background

According to FIRM panels 53063C-0568D, -0564D, -0563D, and -0727D, the majority of the 1% AEP floodplain within the G-CP watersheds is currently designated as Zone A, so no flood depths or base flood elevations are shown within the zones. Some areas are mapped as shaded Zone X, defined as areas of 0.2% AEP flood (Figure 2). In many places, the FEMA SHFAs (some effective since at least 1992) do not match the existing topography and are likely inaccurate. To provide better flood risk data for floodplain management and flood insurance purposes, there is a need to delineate detailed, accurate floodplain boundaries. To provide good estimates of peak flood flow rates for use in hydraulic models, an HSPF hydrologic model, combined with statistical analysis of the model output, is used to develop updated flood frequency peak flows.

1.2.2 Flooding Problems

According to the Glenrose/Central Park Stormwater Management Plan (MWH, 2002), stormwater runoff in the G-CP watersheds flows from property and hillsides, ponds in low-lying areas, and infiltrates into the ground. Over much of the G-CP watersheds, during intense storms or during snowmelt, localized flooding occurs and is associated with topography (slope of the land), nature of the soils, and the location and density of development. Stormwater runoff in the Glenrose and Central Park watersheds runs off property and hillsides, ponds in low-lying areas and infiltrates into the ground. Over much of the watersheds, during intense storms or during snowmelt, localized flooding does occur. However, large flood flows with contributions from all parts of the watershed does not occur.

In the Glenrose watershed, flooding typically occurs locally, caused by ponding in low areas, inadequate swale or culvert capacity, and/or high groundwater affecting infiltration facilities (drywells and swales). In the Central Park watershed, flooding also occurs locally in hillside areas, where development is prone to substantial damage without properly sized and configured integrated stormwater facilities, such as east of Park Rd along Beverly Drive, Center Drive, and Skyline Drive. The lower area of the Central Park watershed is relatively flat and contains substantial single-family residential development. Shallow flooding and ponding in this area occurs primarily along streets.

The stormwater problem description was developed using City of Spokane, City of Spokane Valley, and Spokane County complaint records from residents concerning flooding problems. Complaint records since 1993 were mapped and used for understanding current flooding locations (Figure 4).

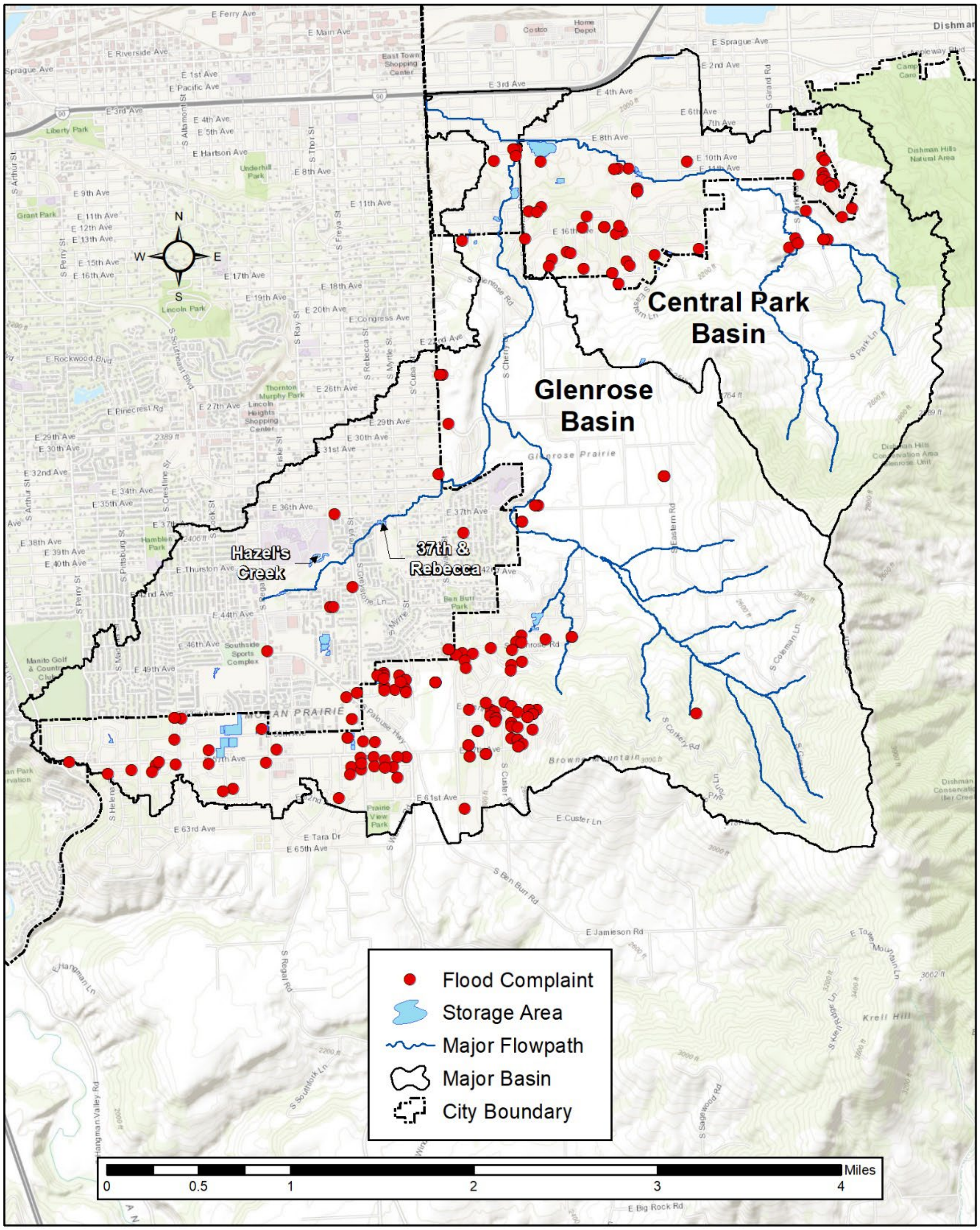

Figure 4: G-CP Flood Complaint, Storage Area and Major Flowpath Locations

1.2.3 Development Stormwater Controls

The principal method of control and disposal of runoff in the G-CP watersheds is through over 900 drywells (WEST, 2023). Most of the drywells have very high infiltration rates, some being measured at over 3 cfs. On the other hand, a number of drywells within the watersheds have experienced problems such as siltation and have reduced infiltration capacities. A number of drywells in the upper portion of the Glenrose watershed have standing water in them.

There are several large retention basins within the G-CP watersheds. While evaluation of these systems was not an element of the watershed study, County staff have indicated that several facilities appear to work adequately, but a majority may not be functioning as required or maintained in a manner to permit proper operation. Major detention basins, including Hazel's Creek and 37th & Rebecca where infiltration rates were tested, were included in the HSPF model developed for the G-CP watersheds (WEST, 2023).

Based on conversations with ALLWEST, subcontracted to evaluate drywell capacities, during the site visit on April 28, 2021, some private water storage facilities (e.g., reservoirs) may exist on private land on Browne's Mountain, located in the upper Glenrose basin within the County; however, the presence of these facilities has not been confirmed and no other information is known. The presence of private storage facilities could vary and reduce the streamflow rates and volumes joining the Glenrose Creek main channel downstream.

2 Hydraulic Model Development

HEC-RAS version 6.6 was used to develop hydraulic models of the G-CP area. The area was modeled in three parts (Figure 5). The Bettman Channel was modeled using an HEC-RAS 1D steady-flow simulation upstream of a large pipe that routes water much further downstream. We determined that the culvert could convey flows up to the 0.2% AEP (500-year) event from the upstream reach of the Bettman channel and that the upstream reach was short enough that flows would not change significantly, and the time of travel is relatively short.

The second model is an HEC-RAS 1D steady-state simulation of Upper Glenrose Channel and its major tributary lying within Spokane County. The upstream flows into the system and flow changes along the channel (due to significant infiltration) were specified using the results of the HSPF hydrologic model. This portion of Glenrose is also steep and the time of travel relatively short.

Further downstream, largely within the City of Spokane Valley, there are few obvious flowpaths and we expected that flows might spread out. This area was modeled using an HEC-RAS 2D model with six inflow locations.

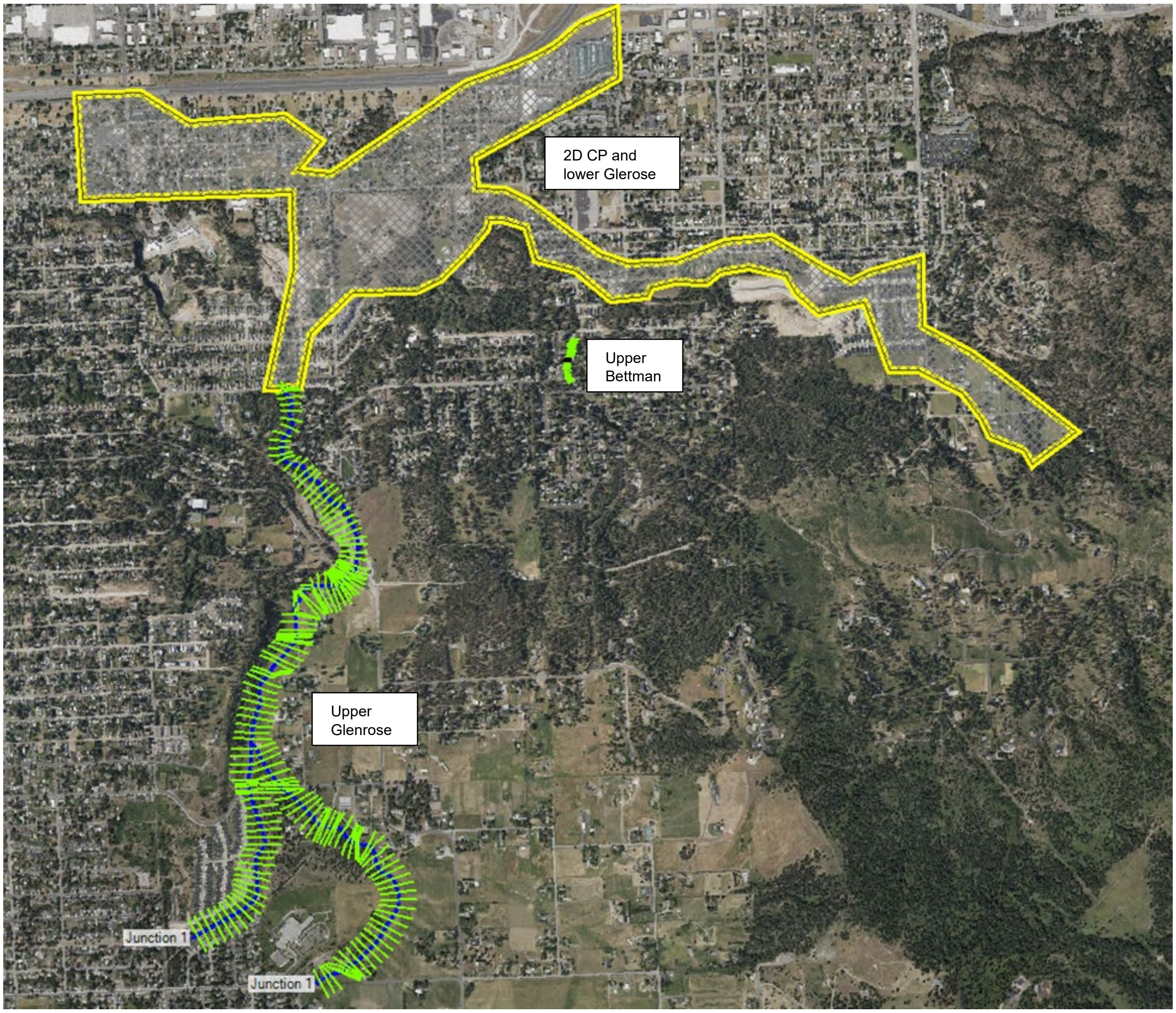

Figure 5: Hydraulic Models Developed

2.1 Terrain Development

Lidar was flown across the entire area in 2015. These data were processed to create a single “bare earth” terrain coverage of the area, including flow channels. Terrain “modifications” were added to the Lidar terrain to reflect elevation changes reported in several LOMRs in the Glenrose and Central Park areas. The most significant modification was from the Taylor Cottage development within Spokane County along the Central Park drainage. The combined elevations are shown in Figure 6 as feet NAVD1988.

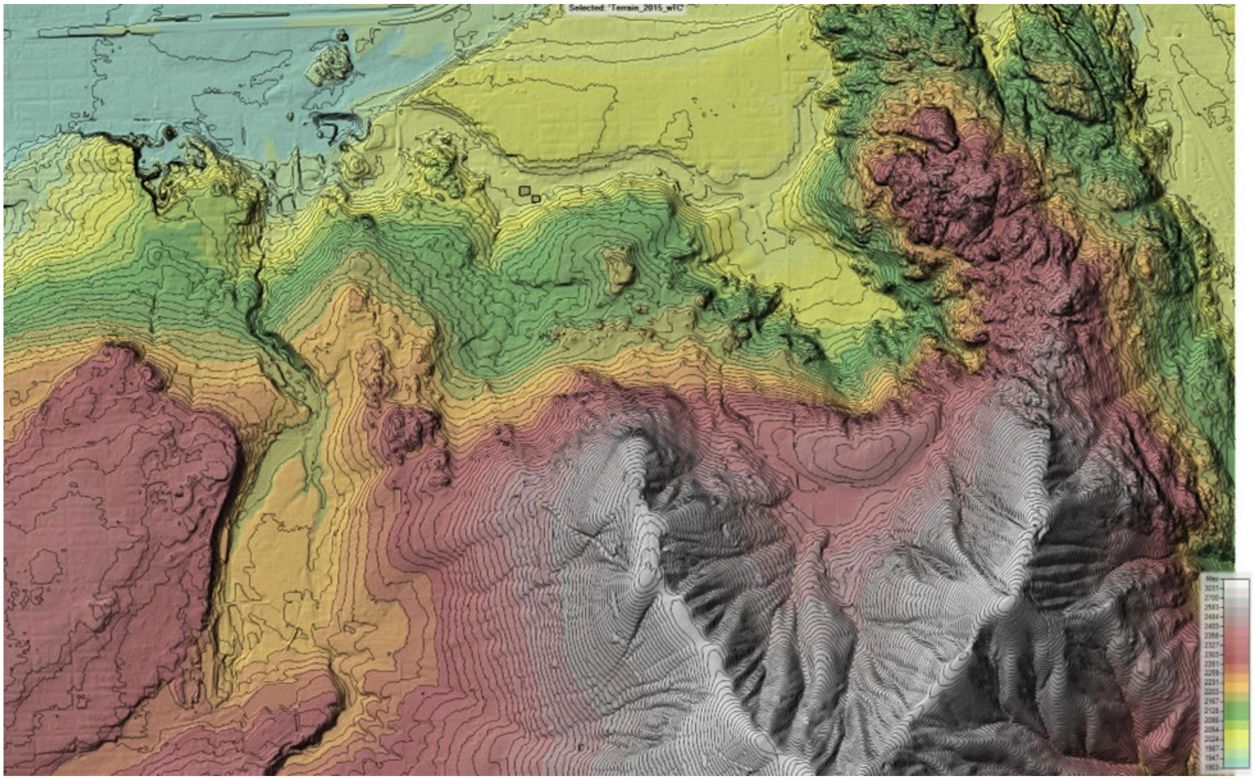

Figure 6: Terrain for the Glenrose-Central Park Area of Spokane County (feet NAVD88)

2.2 Grid Development

2.2.1 One-Dimensional Geometry of Upper Bettman Channel.

Figure 7 shows the one-dimensional cross sections developed to simulate the upper Bettman Channel cut from the combined terrain coverage. The approximate cross-section spacing is 25 feet. There is a single structure in the geometry that includes four, 2.5-feet diameter circular culverts.

Figure 7: Cross Sections for Upper Bettman Channel

2.2.2 One-Dimensional Grid of Upper Glenrose Channel and Tributary.

Figure 8 shows the one-dimensional cross sections developed to simulate the upper Glenrose Channel in Spokane County cut from the combined terrain coverage. The model consists of “upper” and “lower” Glenrose and one major tributary. The approximate along-channel spacing is 100 feet. The model includes one bridge and ten culvert crossings.

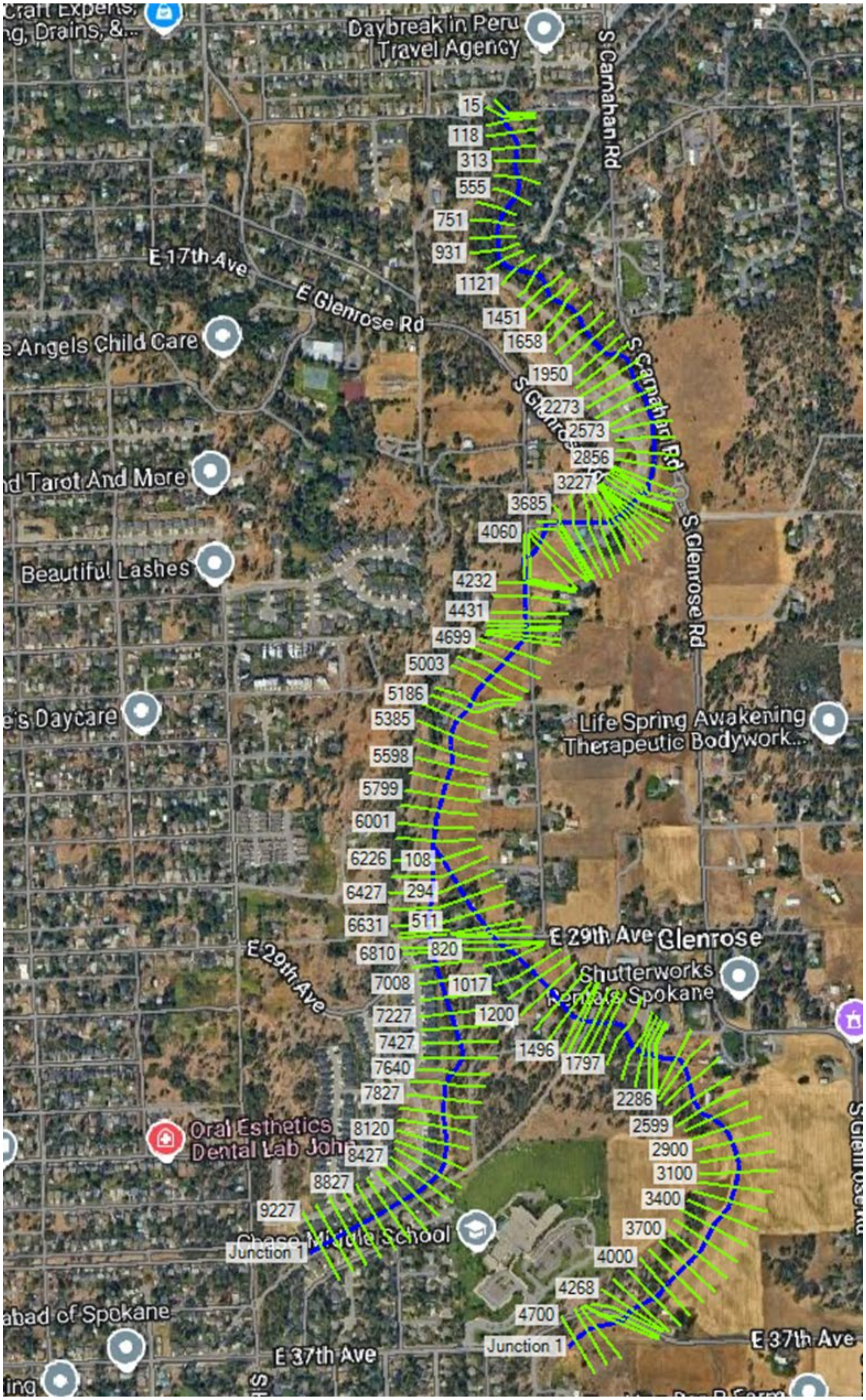

Figure 8: Cross Sections for Upper Glenrose Channel and Tributary

2.2.3 Two-Dimensional Grid of Lower Glenrose and Central Park Area

Using HEC-RAS v. 6.6, a 2D grid was developed for the area shown in Figure 9. The base resolution is 25 feet by 25 feet and a breakline was defined along 8th Street which is the major feature obstructing flows from the south to reach areas further north. The figure also shows boundary condition locations and culverts modeled. The grid has a total of 24,508 cells.

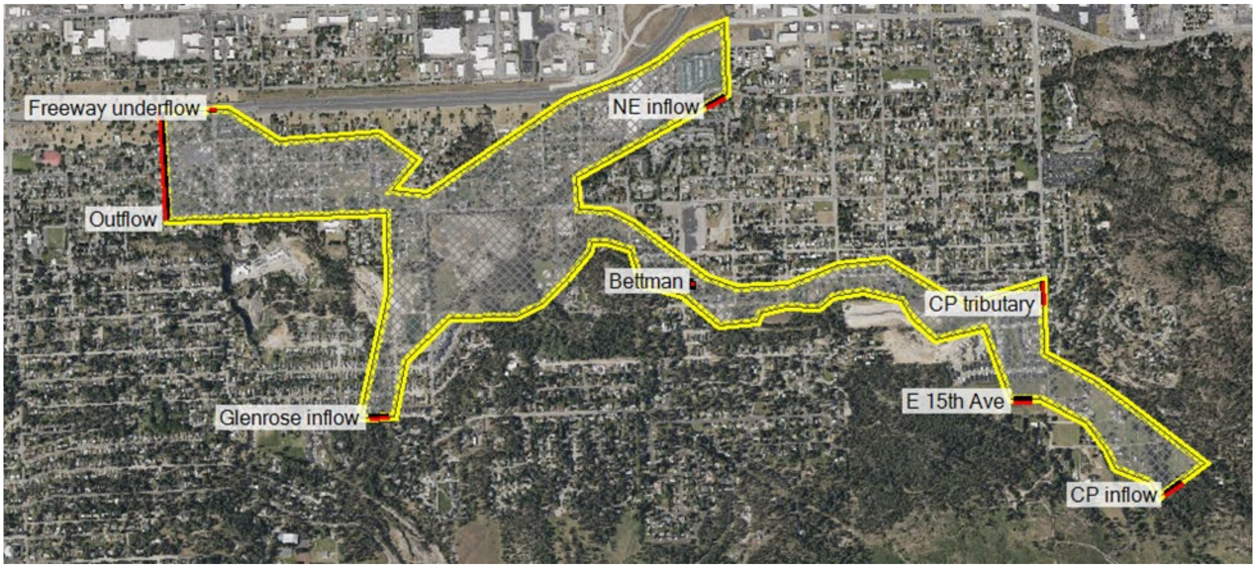

Figure 9: 2D Hydraulic Model Area and Boundary Locations

2.3 Land Cover

Using GIS tools, land cover areas were developed for the modeled areas (Figure 10) and assigned Manning's *n* roughness values (Table 1). Values were selected based on the presence of buildings and the expectation of relatively shallow flows in most areas.

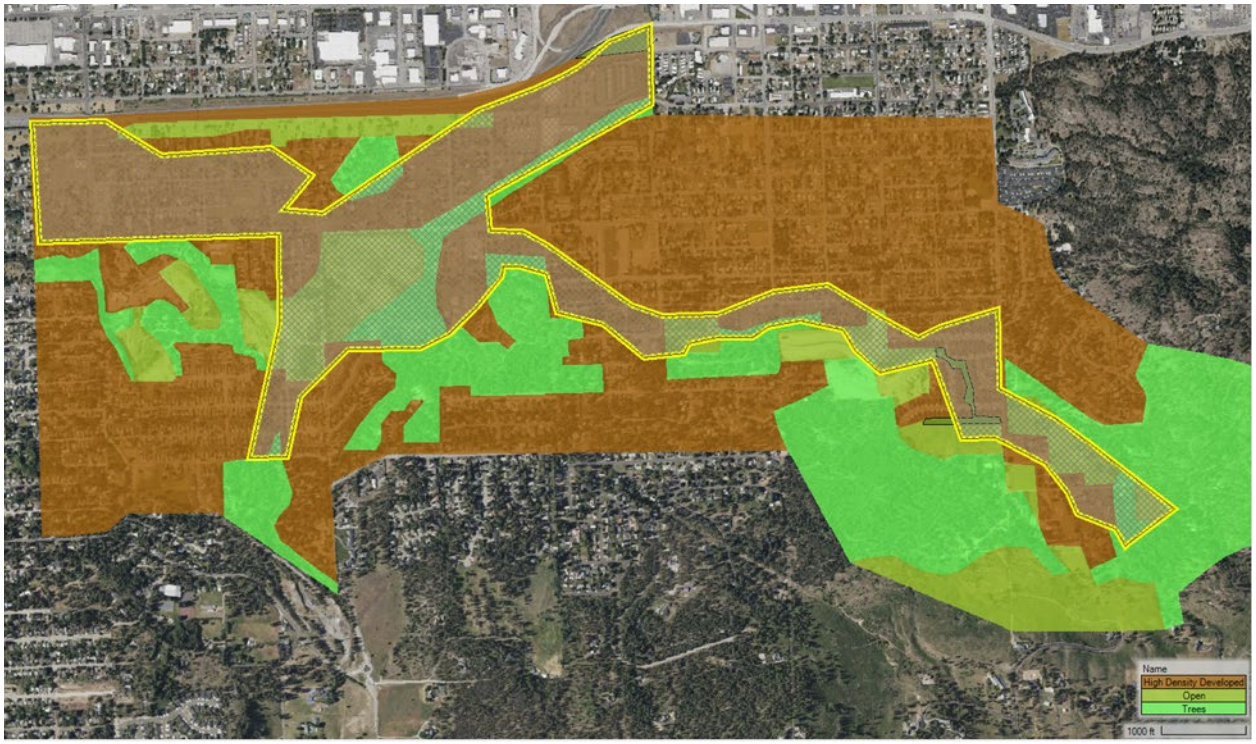

Figure 10: Land Cover in 2D Model Area

Table 1: Manning's *n* Roughness Values for Land Cover Types

Land Cover	Manning's *n*
High Density Developed	0.15
Open Areas	0.05
Trees	0.1

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2.4 Boundary Conditions

Table 2, Table 3, and Table 4 list the inflows for the 10% AEP (10-year), 4% AEP (25-year), 2% AEP (50-year), 1% AEP (100-year) and 0.2% AEP (500 year) events for the Upper Bettman, Upper Glenrose, and G-CP models, respectively. The inflows were developed from the HSPF hydrology model study (WEST, 2023).

Table 2 lists the inflows for the Upper Bettman 1D steady-flow hydraulic model. There are no flow changes along its length. Table 3 lists the flows changes along the Upper Glenrose 1D steady-flow hydraulic model. Flow changes along the lengths of the three reaches were developed from the HSPF hydrology model that includes subbasin inflows and infiltration. The locations of the inflows to the 2D hydraulic model are shown in Figure 9 are shown in red. They were developed by identifying and combining subbasin inflows from the HSPF hydrology model. At the two outflow locations from the northwest portion of the 2D model area, normal depths boundaries with terrain slopes of 0.002 ft/ft were defined.

Table 2: Inflows to Upper Bettman Hydraulic Model (in cfs)

Inflow Location	10-year	25-year	50-year	100-year	500-year
Upper Bettman	8.5	16	22	28	41

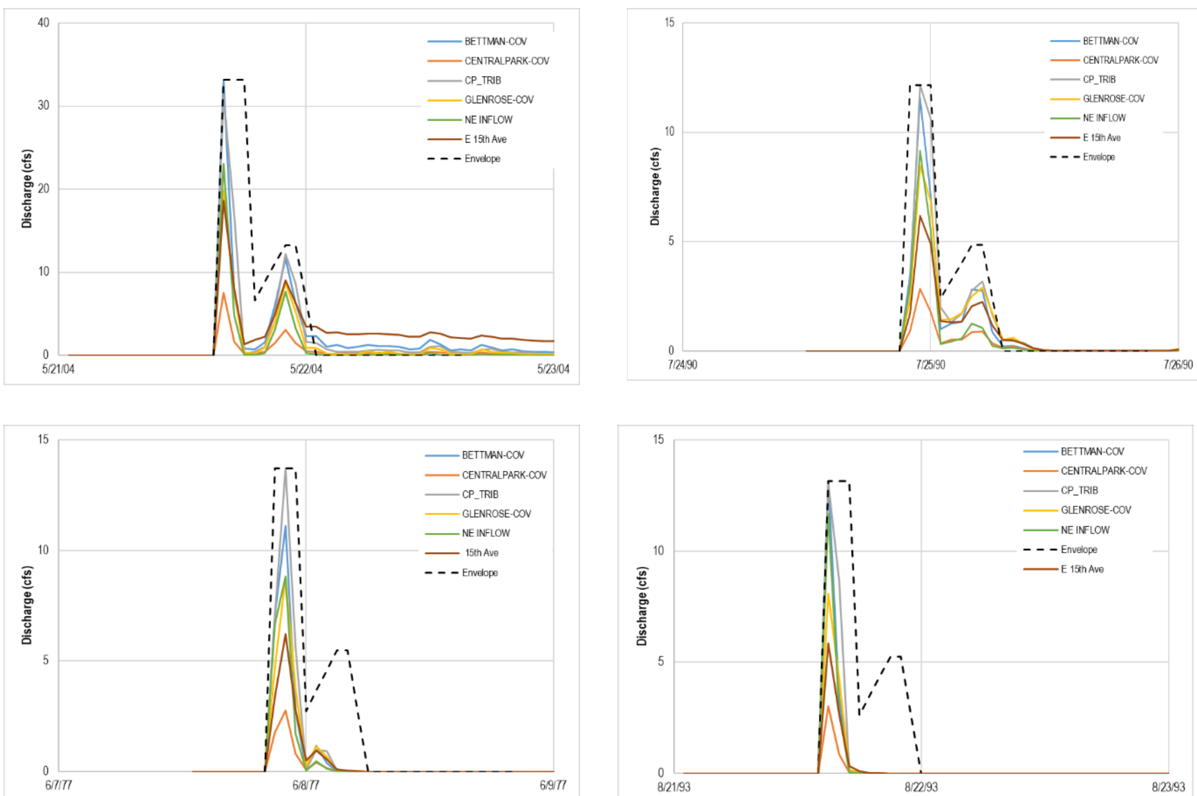
Table 3: Flows in the Upper Glenrose Hydraulic Model (in cfs)

Inflow Location	River Station	10-year	25-year	50-year	100-year	500-year
Upper Glenrose	9227	36	53	70	91	161
Upper Glenrose	7008	38	57	76	99	178
Upper Glenrose	6704	15	22	29	40	76
Upper Glenrose	6094	15	22	29	40	76
Below Confluence	3289	8.6	13	17	24	46
Below Confluence	4700	0.8	1.2	1.6	2.1	4
Tributary	3500	10.6	14.8	19.5	25.9	49
Tributary	2900	13	18.6	25.1	34.1	67.1

Table 4: Inflows to G-CP 2D Hydraulic Model (in cfs)

Inflow Location	10-year	25-year	50-year	100-year	500-year
CP inflow	2.3	3.3	4.5	6.1	12.2
E 15th Ave	3.1	4.6	6.4	9.7	18
CP tributary	9.5	14	18.9	25.5	48
Bettman	9.4	14.2	19.6	27	54
NE Inflow	8	11	15	19	34
Glenrose inflow	6.5	9.2	12.3	16	32

Initial tests of the 2D hydraulic model using "steady-state" inflows indicated that downstream depths and water surface elevations would stabilize after about 16 hours. This would produce significant flooding north of 8th Street where little flooding has been observed historically. And as the inflow locations to the 2D model are spread over a large area, it would be difficult to develop "balanced" inflow hydrographs with a range of timing of the individual inflows and to also include secondary peaks which might influence total inflow volumes. Therefore, we reviewed the top five modeled inflow events from the hydrology model (Figure 11) to see if there was a still conservative but less “severe” way to consider inflow volumes as well as inflow peaks. From Figure 11 we concluded that all these hydrographs could be encompassed by an “envelope” of inflows that ramped up the flows from zero to the peak flow over one hour, maintained the peak flow for three hours, reduced the flow to 20% and then up to 40% of the peak for two hours to capture any secondary peak (Table 5). This method is still conservative but includes the possibility of a secondary peak as seen clearly in the 2004 and 1990 events and partially in the 1977 event. The “envelopes” are illustrated in Figure 11 to show that they would contain all the inflow volumes. Further model testing indicated that many areas are influenced only by the larger flow peak. However, some downstream areas are also influenced by the secondary peak where the volume of inflows is important for flood storage.



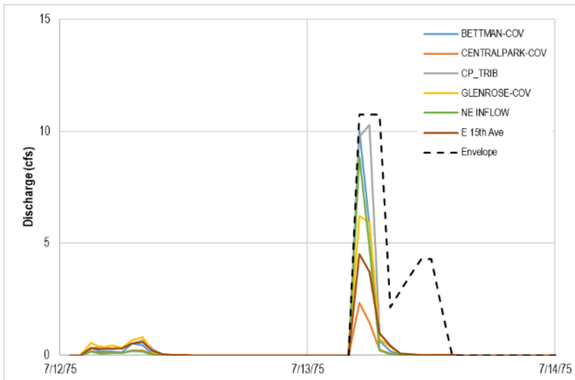


Figure 11: Top Five Largest Hydrographs from HSPF Hydrologic Model and Envelopes

Table 5: Envelope of Inflows to 2D Model

Hour	Fraction of Peak Flow
0	0
1	1
2	1
3	1
4	0.2
5	0.267
6	0.333
7	0.4
8	0.4
9	0.2
10	0

2.5 Sensitivity Analyses

A limited sensitivity analysis was performed on the hydraulic model. Grid sizes of 50 feet and 25 feet were compared. The results indicated that a grid size of 25 feet gave slightly more detailed results, but that the placement of breaklines and lateral structures was more important in modeling inundation extents.

We compared dynamic wave versus diffusion wave simulations and found very similar results. We used the diffusion wave method for all scenarios as the model runs a little faster.

Finally, we compared the number of iterations specified for convergence. There is a cell near the inlet to the E. 15th Avenue culvert, just south of the Taylor Cottages development, that is unstable. Selecting either 10 or 20 iterations made little difference. Therefore, 10 iterations was specified. The instability is related to flows mainly going over E. 15th Avenue rather than through the culvert and has no real impact on overall model results or inundation extents.

2.6 Model Validation

While there are no direct flow measurements to calibrate or validate the 1D or 2D hydraulic models, we noted that during the 2004 event (comparing the peak discharges of Figure 11 to “100-year” values in Table 2 through Table 4), the individual inflows ranged from the 50-year to the 200-year event, based on the plotting positions from the hydrology study (WEST, 2023). Comparing the results of the 2D hydraulic model and the hydrologic model over the modeled inflow locations, the sum of the peak inflows from the 2004 event modeled using HSPF is 114 cfs, compared to the sum of the individual frequency analyses of the 100-year (1%AEP) flows is 103 cfs. This comparison and the volumes of inflows model result in conservative estimates of the resulting floodplain, but significantly less conservative than modeling each inflow as a “steady-state” source to achieve flow-stage convergence throughout the 2D model.

3 Flood Simulations

Each return-interval (10%-0.2% AEP) event was modeled for a duration of 24 hours using the boundary conditions and inflow hydrograph shapes described in Section 2.4. Output hydrographs and mapped results are written to files at 15-minute intervals. The 2D calculations were performed using the diffusion wave option, as depths are quite shallow. The PARDISCO (direct) solver was used with a timestep of 12 seconds.

3.1 Floodplains Analysis

Figure 12 through Figure 16 show the depth floodplains for the 10% (10-year) Annual Exceedance Probability (AEP) event through the 0.2% (500-year) AEP event.

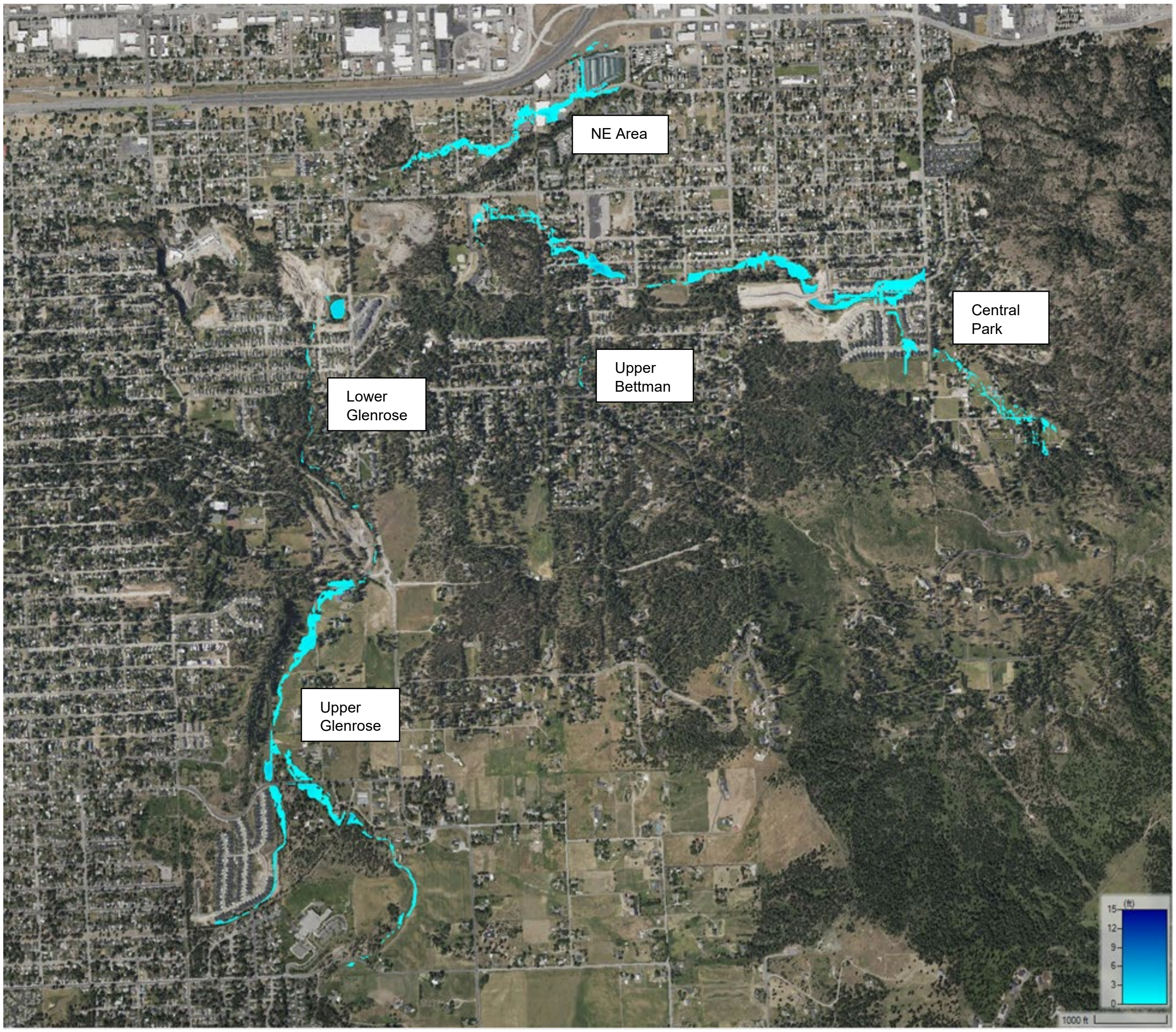


Figure 12: Depth Floodplain for 10% AEP (10-year) Event

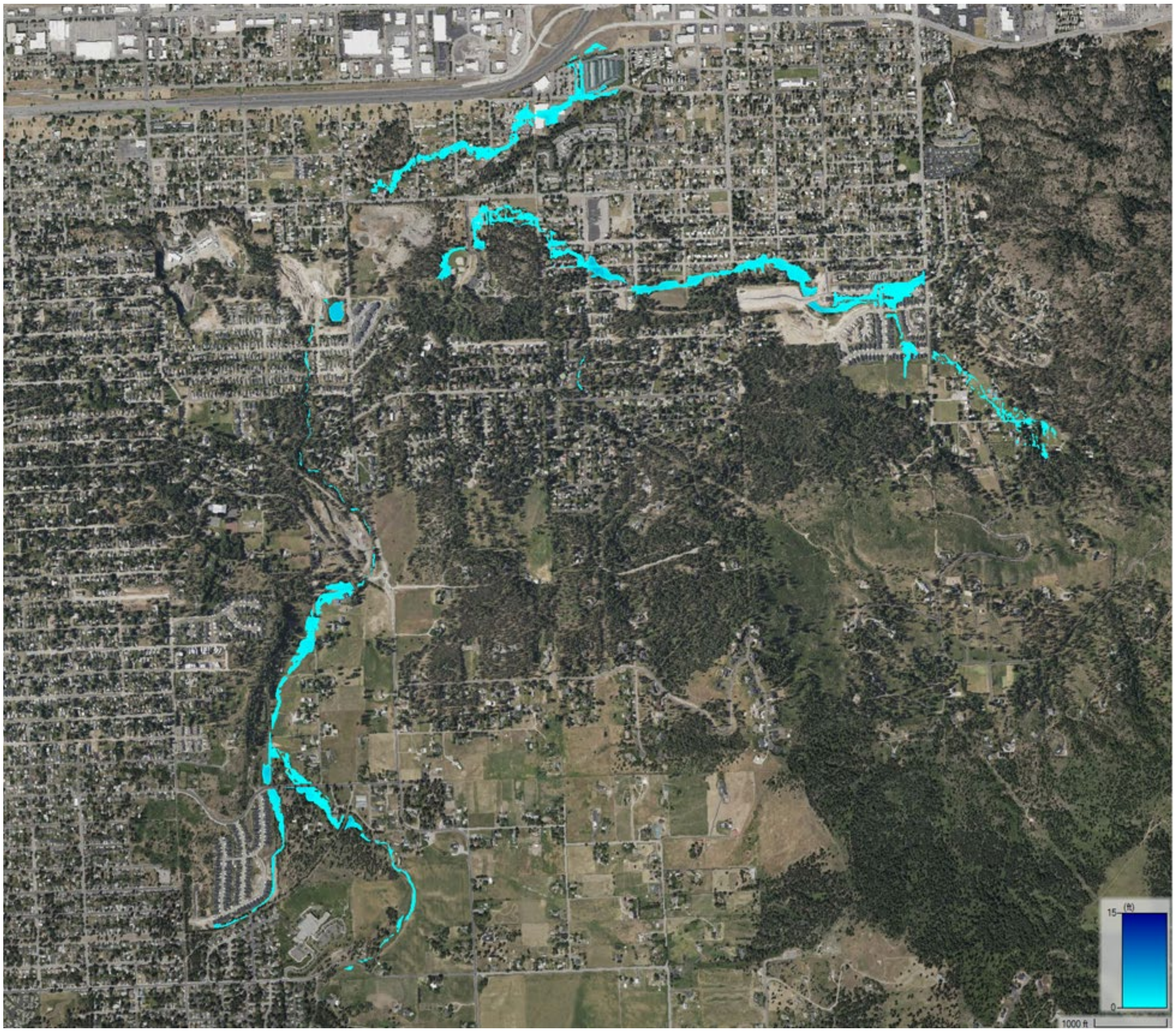


Figure 13: Depth Floodplain for 4% AEP (25-year) Event

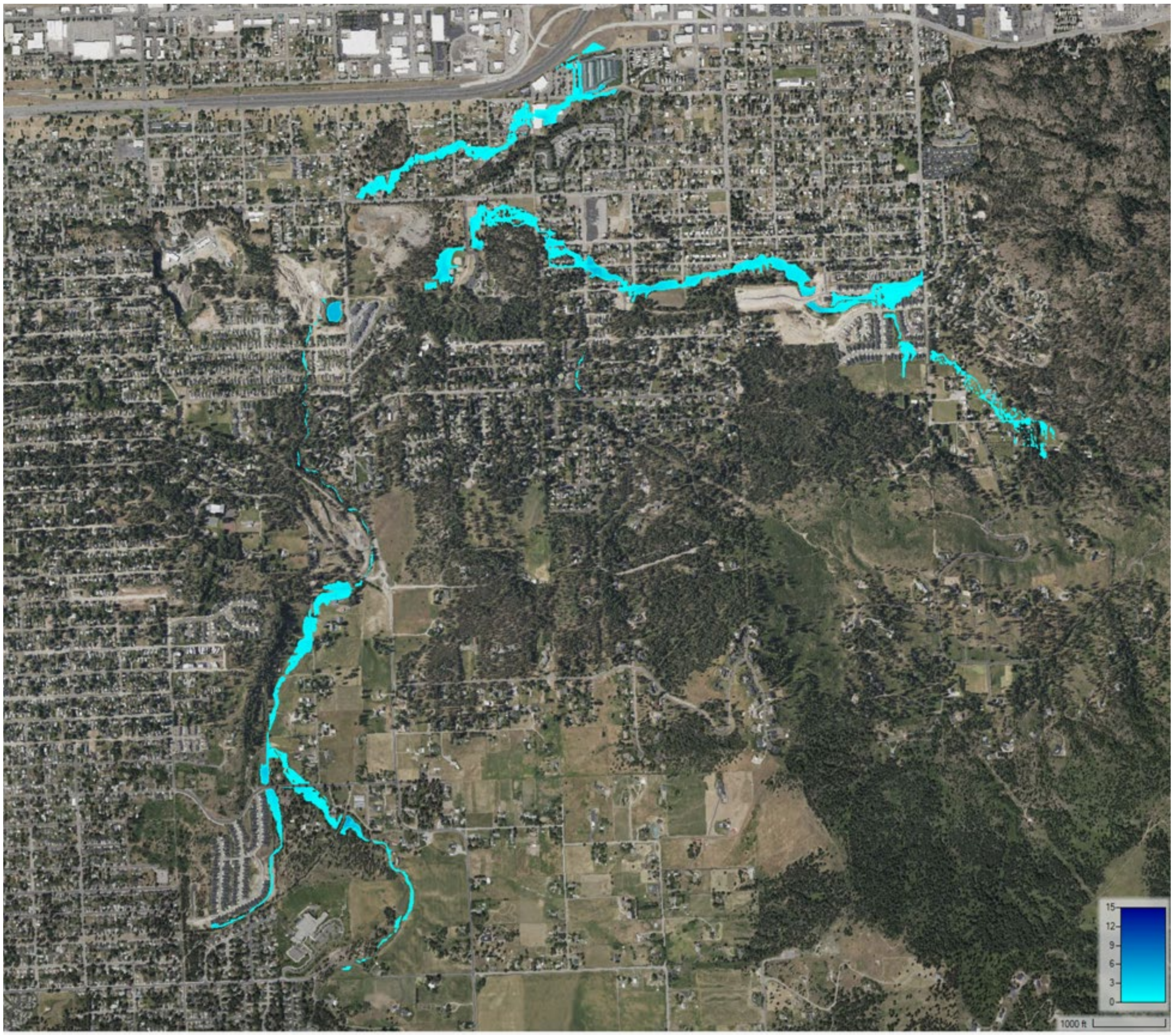


Figure 14: Depth Floodplain for 2% AEP (50-year) Event

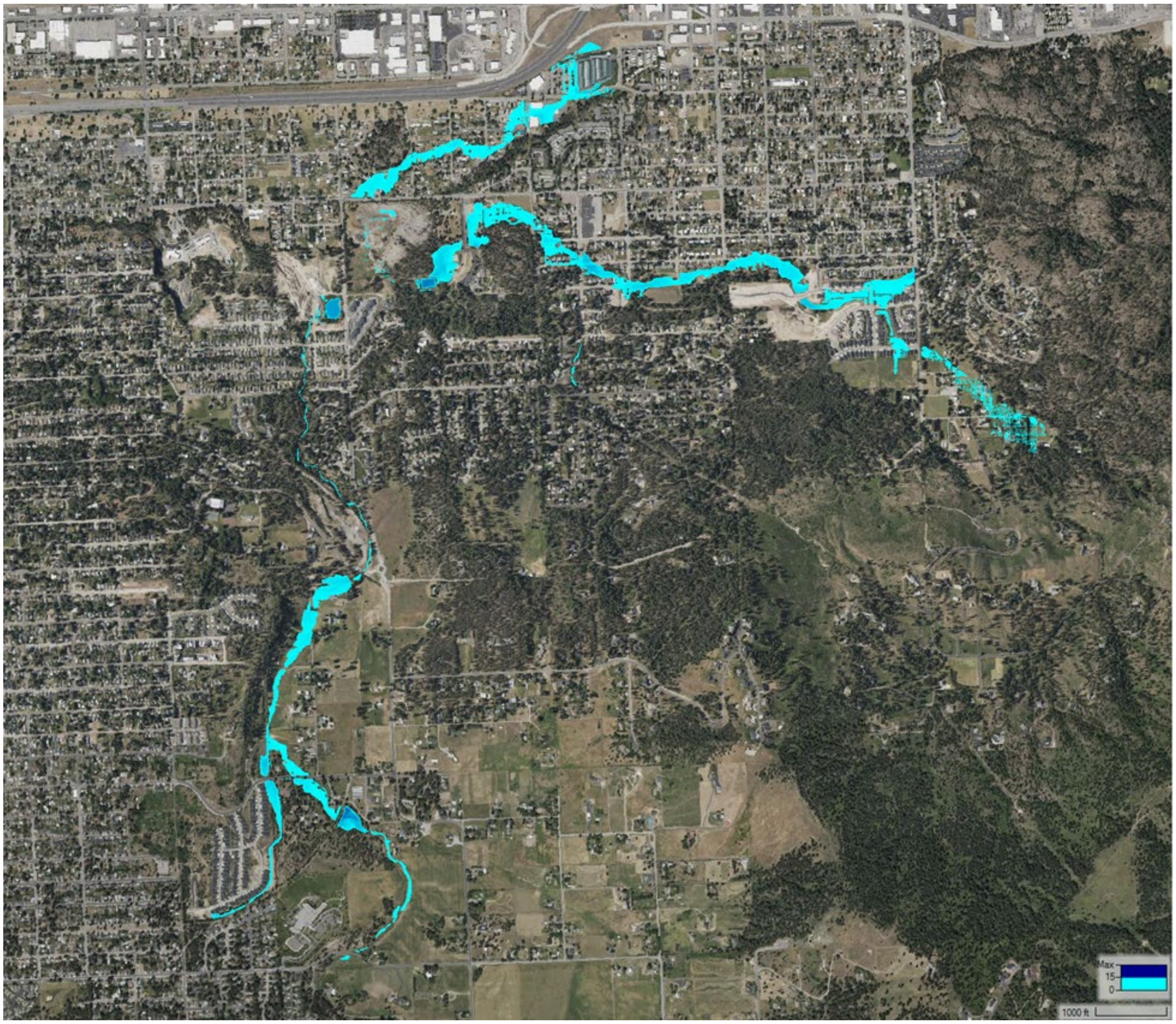


Figure 15: Depth Floodplain for 1% AEP (100-year) Event

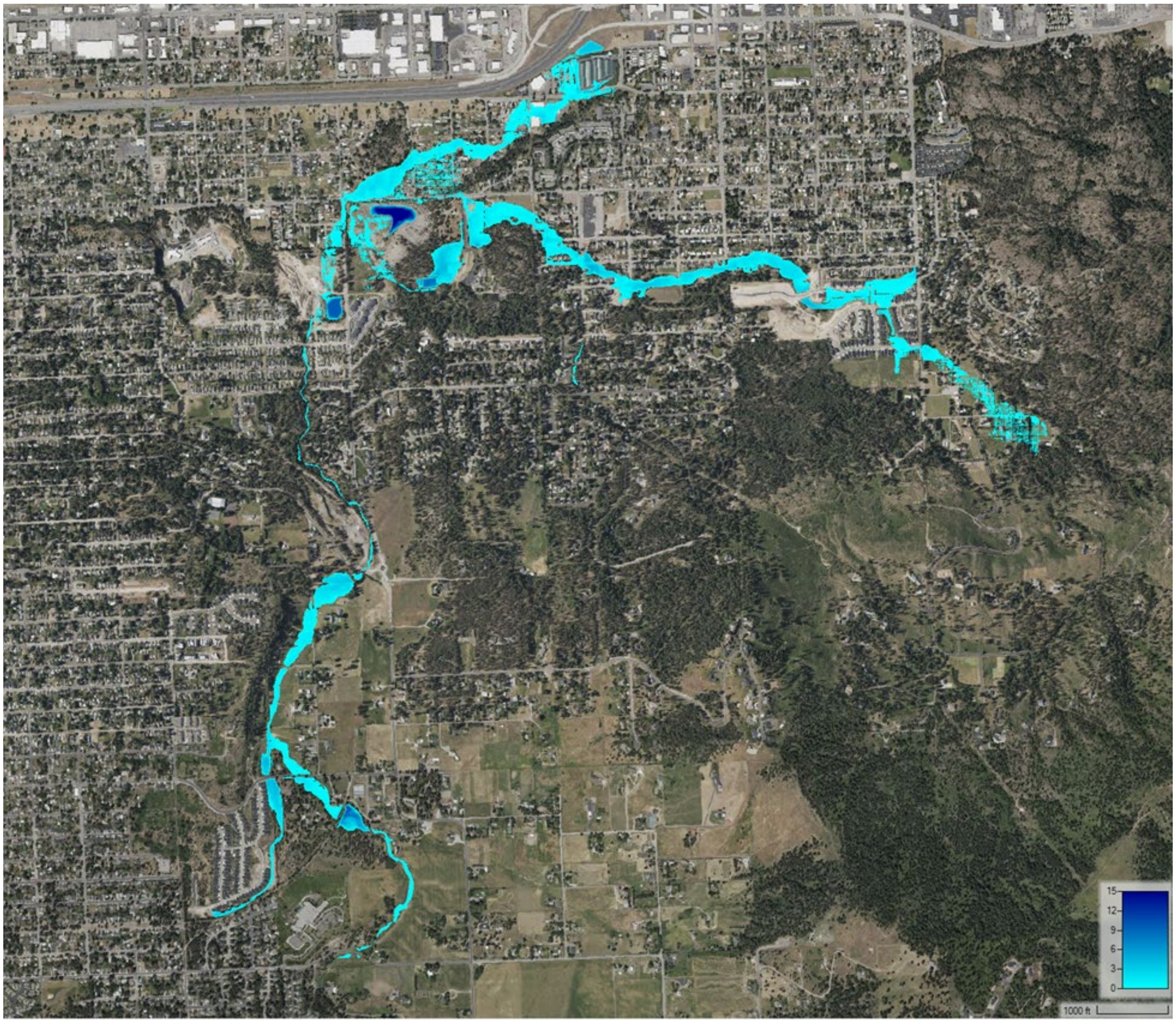


Figure 16: Depth Floodplain for 0.2% AEP (500-year) Event

The results show that the G-CP area has four distinct parts.

The Glenrose channel is relatively steep and generally narrowly confined. Its terminus is the pit near the intersection of E. 8th Avenue and S. Carnahan Road. The pit seems to be large enough to contain flood flows from the Glenrose Channel.

The upper Bettman Channel floodplain is also narrow and terminates at the upstream end of a long pipe that discharges to the Central Park system. The pipe appears to be large enough to pass flood flows.

Inflows from higher ground to the northeast, between E. 4th Avenue and E. 10th Avenue, seem to be the only potential source of inflow flooding north of E. 8th Avenue. Runoff from high ground further to the east is captured by a number of stormwater ponds constructed to the north of E. 4th Avenue.

The Central-Park floodplain is complicated by several factors. Upstream of S. Park Road, the floodplain depths are shallow (generally less than one foot). The culvert under S. Park Road seems adequate to convey these flows to its outlet just north of E. 15th Avenue. Flooding is found in the area of the Taylor Cottages development for two reasons. First, the lowest ground south of E. 15th Avenue appears to be slightly east of the inlet to the E. 15th Avenue culvert and there appears to be no terrain modification to direct inflows this culvert. In the hydraulic model, flows overtop E. 15th Avenue rather than enter this culvert. Further downstream, the channel and culvert designs seem adequate to convey these flows through the residential development. Second, there are flows entering this area across S. Park Road in the vicinity of E. 13th Avenue. The floodplain of these flows includes the northern portions of the Taylor Cottages development. Further downstream, the CP flows are eventually captured by pits to the southeast of the intersection of E 8th Avenue and S. Carnahan Road.

3.2 Floodway Analysis

A floodway analysis was performed along only the Genrose Channel as far north as the intersection of E. 8th Avenue and S. Carnahan Road. Along the length of the 1D hydraulic model of Upper Glenrose Channel within Spokane County, the floodway was developed using equal conveyance reduction until all water level increases (surcharges) between the floodplain and floodway simulations were less than or equal to one foot. In the lower reach of the Glenrose Channel, within the City of Spokane Valley, the terrain was modified to remove areas with development or areas with wide floodplains, and the 2D model run to confirm no increases greater than one foot. The resulting floodway is shown in Figure 17 and the floodway data table for upper Glenrose Channel is shown in Table 6. In Figure 17, the floodway is shown in pink and the floodplain is shown as a combination of the blue and pink areas. The blue area alone is termed the “floodway fringe”.

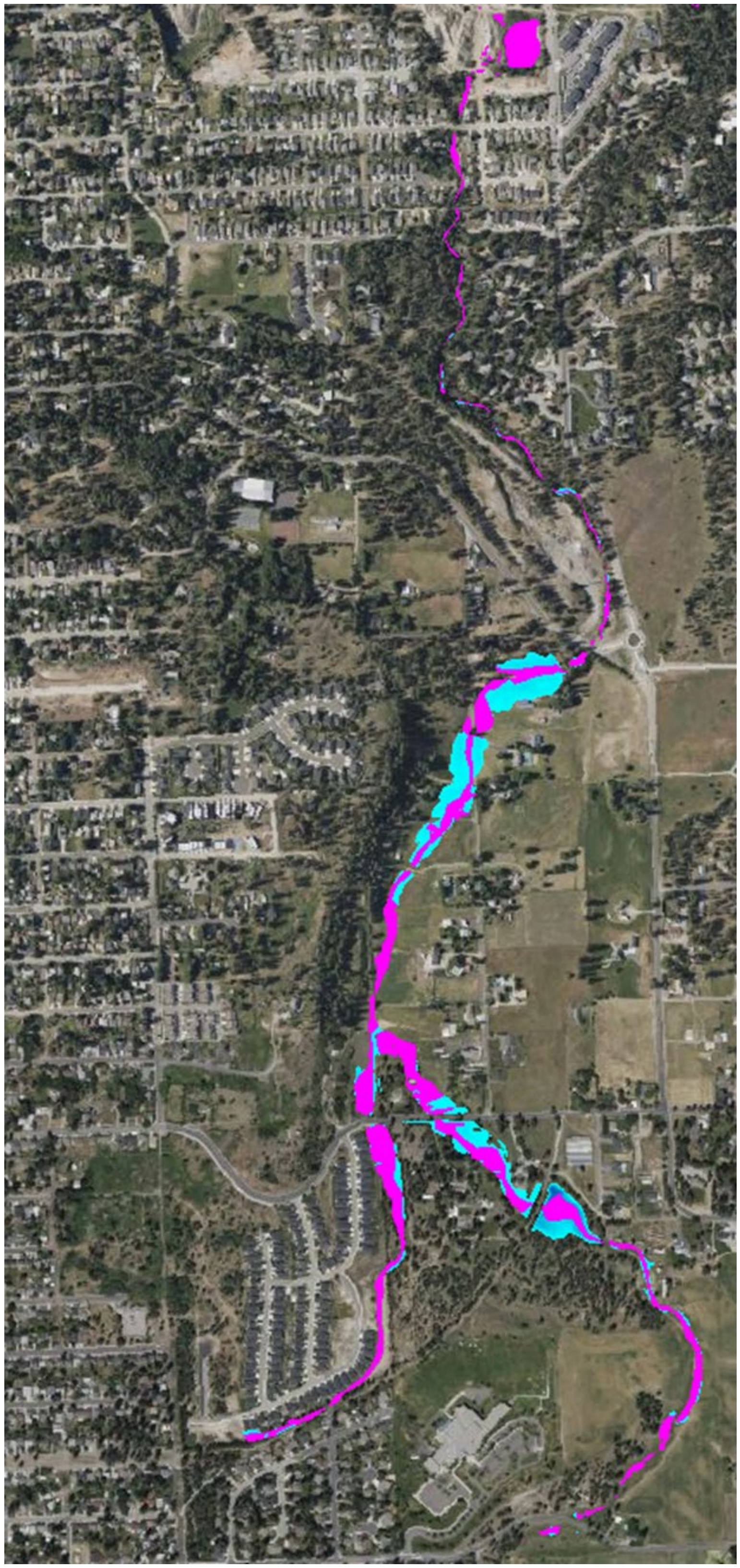


Figure 17: 100-year floodplain (pink plus blue) and Floodway (pink) along the Glenrose Channel

Table 6: Floodway Data Table

Reach	Station	Water Surface Elevation (ft NAVD)	Floodway Elevation (ft NAVD)	Surcharge (ft)
Upper Glenrose	9227	2265.64	2266.54	0.9
Upper Glenrose	9127	2265.26	2266.09	0.83
Upper Glenrose	9027	2265.14	2266.06	0.92
Upper Glenrose	8927	2264.79	2265.38	0.59
Upper Glenrose	8827	2263.11	2263.11	0
Upper Glenrose	8727	2257.9	2257.9	0
Upper Glenrose	8627	2249.98	2249.98	0
Upper Glenrose	8527	2245.13	2245.13	0
Upper Glenrose	8427	2240.22	2240.22	0
Upper Glenrose	8327	2234.74	2234.74	0
Upper Glenrose	8228	2229.17	2229.17	0
Upper Glenrose	8120	2224.9	2224.9	0
Upper Glenrose	8014	2221.37	2221.37	0
Upper Glenrose	7928	2216.6	2216.6	0
Upper Glenrose	7827	2215.54	2215.54	0
Upper Glenrose	7732	2214.88	2214.88	0
Upper Glenrose	7640	2212.6	2212.63	0.03
Upper Glenrose	7527	2211.63	2211.63	0
Upper Glenrose	7427	2210.07	2210.07	0
Upper Glenrose	7327	2209.53	2209.56	0.03
Upper Glenrose	7227	2208.85	2208.9	0.05
Upper Glenrose	7123	2208.66	2208.7	0.04
Upper Glenrose	7008	2208.61	2208.62	0.01
Upper Glenrose	6896	2208.6	2208.6	0
Upper Glenrose	6810	2208.57	2208.57	0
Upper Glenrose	6786	2208.44	2208.44	0
Upper Glenrose	6704	2205.69	2205.75	0.06
Upper Glenrose	6701	2205.71	2205.77	0.06
Upper Glenrose	6631	2205.71	2205.77	0.06
Upper Glenrose	6526	2205.71	2205.77	0.06
Upper Glenrose	6427	2205.7	2205.75	0.05
Upper Glenrose	6327	2205.66	2205.68	0.02
Upper Glenrose	6226	2205.6	2205.61	0.01
Below Confluence	6094	2205.52	2205.52	0

Below Confluence	6001	2205	2205	0
Below Confluence	5898	2203.41	2203.41	0
Below Confluence	5799	2202.33	2202.33	0
Below Confluence	5699	2201.82	2201.82	0
Below Confluence	5598	2201.38	2201.38	0
Below Confluence	5498	2201.07	2201.11	0.04
Below Confluence	5385	2200.63	2200.7	0.07
Below Confluence	5277	2199.53	2199.58	0.05
Below Confluence	5186	2199.17	2199.32	0.15
Below Confluence	5129	2199.04	2199.25	0.21
Below Confluence	5003	2198.68	2198.98	0.3
Below Confluence	4900	2198.52	2198.72	0.2
Below Confluence	4798	2198.14	2198.5	0.36
Below Confluence	4699	2198.09	2198.42	0.33
Below Confluence	4608	2198.08	2198.39	0.31
Below Confluence	4549	2198.07	2198.37	0.3
Below Confluence	4543	2198.06	2198.35	0.29
Below Confluence	4517	2197.2	2197.74	0.54
Below Confluence	4513	2197.1	2197.59	0.49
Below Confluence	4431	2197.01	2197.32	0.31
Below Confluence	4325	2196.98	2197.24	0.26
Below Confluence	4232	2196.96	2197.19	0.23
Below Confluence	4060	2196.01	2196.01	0
Below Confluence	4030	2194.99	2195.41	0.42
Below Confluence	4027	2194.56	2195.33	0.77
Below Confluence	3897	2194.54	2195.31	0.77
Below Confluence	3827	2194.48	2195.18	0.7
Below Confluence	3794	2194.48	2194.57	0.09
Below Confluence	3685	2194.47	2194.52	0.05
Below Confluence	3602	2194.47	2194.5	0.03
Below Confluence	3503	2194.46	2194.48	0.02
Below Confluence	3424	2194.46	2194.47	0.01
Below Confluence	3384	2194.46	2194.46	0
Below Confluence	3340	2194.37	2194.37	0
Below Confluence	3289	2192.7	2192.71	0.01
Below Confluence	3250	2192.68	2192.68	0
Below Confluence	3227	2192.66	2192.66	0
Below Confluence	3192	2192.64	2192.64	0

Below Confluence	3160	2192.57	2192.57	0
Below Confluence	3119	2192.5	2192.5	0
Below Confluence	3101	2192.51	2192.51	0
Below Confluence	3075	2192.37	2192.37	0
Below Confluence	3035	2191.84	2191.84	0
Below Confluence	2957	2191.33	2191.33	0
Below Confluence	2856	2189.34	2189.34	0
Below Confluence	2773	2188.25	2188.26	0.01
Below Confluence	2671	2186.49	2186.51	0.02
Below Confluence	2573	2183.02	2183.03	0.01
Below Confluence	2470	2178.24	2178.28	0.04
Below Confluence	2370	2174.03	2174.04	0.01
Below Confluence	2273	2171.26	2171.26	0
Below Confluence	2173	2166.9	2166.9	0
Below Confluence	2054	2161.85	2161.97	0.12
Below Confluence	1950	2157.6	2157.6	0
Below Confluence	1851	2147.85	2147.85	0
Below Confluence	1764	2141.64	2141.65	0.01
Below Confluence	1658	2138.18	2138.19	0.01
Below Confluence	1550	2134.48	2134.48	0
Below Confluence	1451	2128.34	2128.34	0
Below Confluence	1364	2123.29	2123.3	0.01
Below Confluence	1243	2118.86	2118.86	0
Below Confluence	1121	2114.26	2114.27	0.01
Below Confluence	1011	2106.01	2106.02	0.01
Below Confluence	931	2099.33	2099.33	0
Below Confluence	846	2093.76	2093.77	0.01
Below Confluence	751	2087.14	2087.15	0.01
Below Confluence	666	2082.51	2082.52	0.01
Below Confluence	555	2077.11	2077.11	0
Below Confluence	424	2068.86	2068.86	0
Below Confluence	313	2059.32	2059.32	0
Below Confluence	220	2053.05	2053.05	0
Below Confluence	118	2047.57	2047.57	0
Below Confluence	25	2042.33	2042.33	0
Below Confluence	15	2039.93	2039.93	0
Below Confluence	5	2035.03	2035.03	0
Tributary	4700	2257.15	2257.15	0

Tributary	4600	2254.7	2254.7	0
Tributary	4500	2253.83	2253.83	0
Tributary	4355	2252.72	2252.73	0.01
Tributary	4305	2250.89	2250.89	0
Tributary	4268	2248.58	2248.58	0
Tributary	4200	2248.06	2248.06	0
Tributary	4100	2247.58	2247.58	0
Tributary	4000	2246.88	2246.88	0
Tributary	3900	2245.33	2245.33	0
Tributary	3800	2244.87	2244.87	0
Tributary	3700	2243.98	2243.98	0
Tributary	3600	2243.37	2243.37	0
Tributary	3500	2242.8	2242.8	0
Tributary	3400	2242.07	2242.07	0
Tributary	3300	2240.97	2240.98	0.01
Tributary	3200	2239.74	2239.73	-0.01
Tributary	3100	2238.64	2238.65	0.01
Tributary	3000	2237.69	2237.68	-0.01
Tributary	2900	2236.98	2236.99	0.01
Tributary	2800	2236.32	2236.36	0.04
Tributary	2700	2234.69	2234.68	-0.01
Tributary	2599	2232.93	2233	0.07
Tributary	2508	2232.12	2232.21	0.09
Tributary	2397	2230.37	2230.38	0.01
Tributary	2286	2229.77	2229.77	0
Tributary	2214	2229.11	2229.11	0
Tributary	2082	2228.45	2228.45	0
Tributary	2077	2228.08	2228.08	0
Tributary	2042	2225.46	2225.51	0.05
Tributary	1991	2225.51	2225.51	0
Tributary	1926	2225.51	2225.51	0
Tributary	1797	2225.51	2225.51	0
Tributary	1684	2225.51	2225.51	0
Tributary	1584	2225.51	2225.51	0
Tributary	1581	2225.5	2225.5	0
Tributary	1512	2217.66	2217.66	0
Tributary	1496	2216.48	2216.5	0.02
Tributary	1400	2216.18	2216.25	0.07

Tributary	1300	2215.55	2215.62	0.07
Tributary	1200	2214.58	2214.73	0.15
Tributary	1100	2213.72	2213.77	0.05
Tributary	1017	2213.03	2213.37	0.34
Tributary	902	2213	2213.34	0.34
Tributary	820	2213	2213.32	0.32
Tributary	752	2213	2213.32	0.32
Tributary	700	2211.15	2211.23	0.08
Tributary	676	2210.09	2210.37	0.28
Tributary	616	2209.8	2210.03	0.23
Tributary	511	2208.88	2208.91	0.03
Tributary	394	2207.94	2207.95	0.01
Tributary	294	2206.94	2206.94	0
Tributary	202	2206.41	2206.41	0
Tributary	108	2205.83	2205.83	0

4 High-Level Mitigation Analysis

(TO BE WRITTEN LATER)

5 Conclusions And Recommendations

Three hydraulic models were developed for the FIS study of Glenrose and Central Park (G-CP) Channels in the City Spokane Valley and parts of unincorporated Spokane County, Washington. They include a 1D steady-state HEC-RAS model of the Bettman Channel upstream of a pipe that conveys stormwater to the CP system, a 1D steady-state HEC-RAS model of Upper Glenrose Channel within Spokane County, and a 2D HEC-RAS model of the lower Glenrose Channel within the City of Spokane Valley and the CP system, where flows tend to spread out rather than following clear channels.

The models were run for a range of inflows from the 10% (10-year) Annual Exceedance Probability (AEP) event to the 0.2% (500-year) AEP event. 1% AEP (100-year) floodways were developed for the Glenrose Channel from its upstream extents to approximately the intersection of E. 8th Avenue and S. Carnahan Road. The communities requested no other floodways.

The key findings of the hydraulic analysis are:

- The Glenrose channel is relatively steep and generally narrowly confined. Its terminus is the pit near the intersection of E. 8th Avenue and S. Carnahan Road. The pit seems to be large enough to contain flood flows from the Glenrose Channel.

- The upper Bettman Channel floodplain is narrow and terminates at the upstream end of a long pipe that discharges to the Central Park system. The pipe appears to be large enough to pass flood flows.

- Inflows from higher ground to the northeast of E 8th Avenue seems to be the only potential source of inflow flooding north of E. 8th Avenue.
- Runoff from the high ground further to the east is captured by a number of stormwater ponds constructed to the north of E. 4th Avenue.
- The culvert under S. Park Road seems adequate to convey CP flows to its outlet just north of E. 15th Avenue.
- The lowest ground south of E. 15th Avenue appears to be slightly east of the inlet to the E. 15th Avenue culvert and there appears to be no terrain modifications to direct flows from the south to this inlet. In the hydraulic model, flows overtop E. 15th Avenue rather than enter this culvert.
- The terrain modifications and culverts seem adequate to convey flows from CP and north of E. 15th Avenue through the Taylor Cottage development.
- Flows entering the northern part of the Taylor Cottages development, across S. Park Road in the vicinity of E. 13th Avenue, would flood northern portions of the development.
- Further downstream, the CP floods are eventually captured by pits to the southeast of the intersection of E. 8th Avenue and S. Carnahan Road.

The following recommendations consider ways to address potential flooding in the G-CP system:

- Terrain modification to direct flows to the inlet of the culvert under E. 15th Avenue should prevent road overtopping and potential local flooding. If directed to the culvert leading to the engineered channel through the Taylor Cottages development, we would not expect further flooding.
- Flood mitigation, perhaps additional dry wells along the path of the CP tributary upstream of S. Park Road in the vicinity of E. 13th Avenue, could reduce or eliminate this flooding source. They could be designed to capture the maximum 100-year flow rate of 25.5 cfs up to the maximum 500-year flow rate of 48 cfs.
- Flooding north of E. 8th Avenue from high ground to the east could be reduced or eliminated. This might be accomplished by additional dry wells on the higher ground generally bounded by E. 4th and 10th Avenues and S. Fancher and S. Eastern Roads, and/or flood storage. Dry wells could be placed and designed to capture the maximum 100-year flow of 19 cfs up to the maximum 500-year flow of 34 cfs. Flood storage only could be designed capture up to 8.2 acre-feet for the 100-year event up to 14.6 ace-feet for the 500-year event. The storage estimates are conservative by the same amount that inflow volumes may be overestimated.

6 References

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