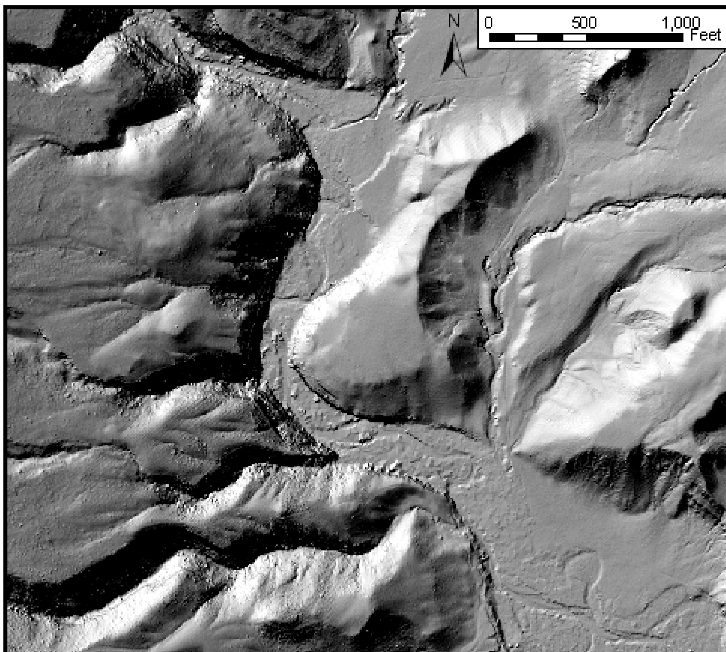
Dullknife Reservoir
Dam Breach Analysis

Johnson County, Wyoming

December 2004



shaded relief image from LIDAR grid – canyon mouth

near Canyon Mouth – North Fork Powder River

emergency spillway - Dullknife Reservoir

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NRCS

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ROCKY MOUNTAIN ENGINEERING TEAM

Lakewood, Colorado

December 22, 2004

Dullknife Reservoir Dam Breach Analysis

Job Number: WY0300
Short Job Description: Dullknfe dam breach analysis.
Location: Johnson County, Wyoming on the North Fork Powder River and Powder River.

Summary: Predictions have been made of the probable extent and timing of flows greater than a 10-year event resulting from the catastrophic breach of Dullknife Reservoir. This report details the dam breach analysis performed on the reservoir for the purpose of hazard classification and an emergency action plan.

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ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance provided by numerous individuals in this effort, including Randy Wiggins, Wyoming NRCS GIS Specialist; Jim Kelly, GIS Technician; and Kenny Legleiter, NRCS Cartogropher. Also, the assistance of Allison Engle, Kaycee District Conservationist; Frank Cure, Engineering Technician; and Christine Campbell, Secretary are greatly appreciated.

INTRODUCTION

This report details the methods and results of a dam breach analysis performed on the Dullknife Reservoir of Johnson County, Wyoming. The analysis consists of breach hydrograph development and hydrograph routing through the stream valleys, ranches, and communities below the structure. This report is intended for use by the NRCS for hazard classification and economic impact analysis and the NRCS, the North Fork Water Users Association, and local emergency officials for the development of an emergency action plan.

The Dullknife reservoir (Figures 2 and 3) is located on the North Fork of the Powder River at an elevation of 8100 feet in the Bighorn Mountains. Average precipitation within the reservoir's 33.9 square mile watershed varies from 23 to 27 inches, according to PRISM. The embankment dam has a maximum height of about 79 feet, with a crest elevation of 8152 feet and associated storage of about 5100 ac-ft. At the emergency spillway crest elevation of 8146 feet the associated reservoir storage is 4220 ac-ft. These volumes do not account for accumulated sediment since construction in the mid- 1960s.

This analysis is sufficient for the determination of the hazard classification, the determination of economic impact from inundation, and for the development of an emergency action plan for the catastrophic breach of the Dullknife embankment. The hazard classification is needed for possible rehabilitation of this structure under the dam rehabilitation program, due to severe erosion of the emergency spillway (Figure 1) and poor performance of the principal spillway.

Figure 1: Emergency spillway, Dullknife reservoir.

Due to the assumptions regarding the mechanism of failure as well as limitations in the understanding of and the ability to model unsteady flow dynamics of the large, severe and abrupt debris-saturated flood wave that would result from an embankment failure, these modeling results are approximate. **The nature and limitations of the predictions provided in this report must be kept in mind when using these results.**

This report details the methodology used to determine the likely effects of a catastrophic breach. The primary sections include an Introduction, Breach Hydrograph Development, Hydrograph Routing, and Likely Inundation Extent and Timing. In addition, most likely inundation maps, modeling output tables, and streamgage flood frequency computations are included in three appendices. **For the results of this analysis, see the Likely Inundation Extent and Timing section and the Maximum Likely Inundation mapping of Appendix A.**

Figure 2: Dullknife reservoir watershed (33.9 square miles).

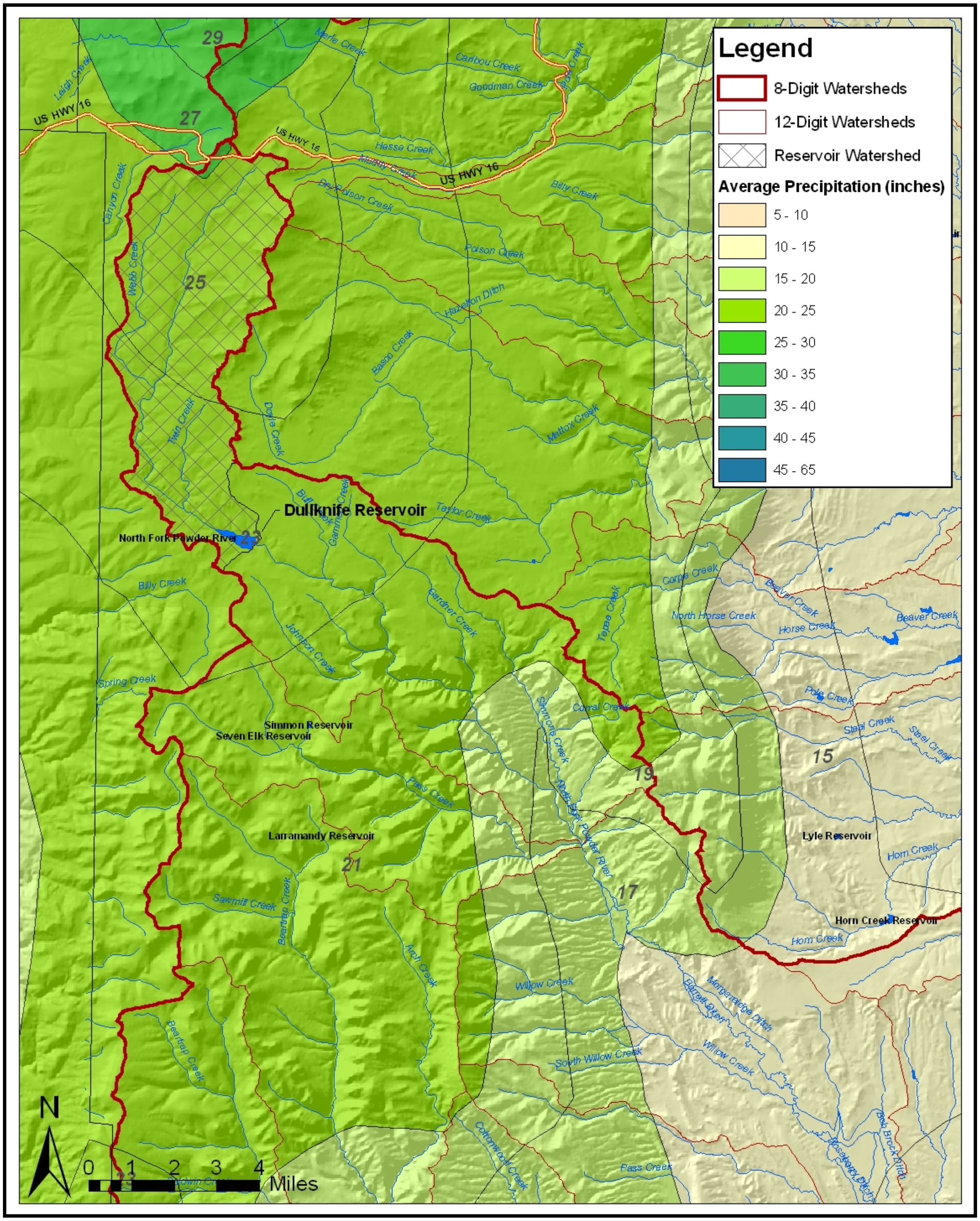


Figure 3: Region of analysis, mountainous portion. Shaded relief, average precipitation (PRISM) estimates, reservoirs and lakes, and the 12- and 8-digit watershed polygons are shown. The Dullknife Reservoir watershed is shown cross-hatched.

BREACH HYDROGRAPH DEVELOPMENT

As mentioned in Froehlich 1995a, the International Commission on Large Dams reports that roughly a third of embankment dam failures are caused by overtopping due to inadequate spillway capacity; another third result from piping failure; and the last third result from embankment sliding, embankment settlement, and inadequate wave protection. An overtopping failure is modeled in this analysis, which is the most likely worst-case failure type in this situation.

Figures 4 through 6 illustrate the characteristics of the 79 foot high embankment.

Figure 4: Dullknife Embankment, downstream face.

Figure 5: Dullknife Embankment, upstream.

Figure 6: Dullknife Embankment, downstream surface condition.

The breach hydrograph was developed using the breach subroutine in HEC-RAS 3.1.2. A sine wave breach progression was chosen to simulate the overtopping failure, with a resulting trapezoidal breach form. Breach characteristics used in the modeling include reservoir volume, average breach width, breach side slopes, and time-to-peak estimates. The emergency spillway maximum flow was modeled to be 2650 cfs. Initial flow for an overtopping event was assumed to be only passing through the emergency spillway – the principal spillway was assumed to be blocked by ice, a common situation in the spring for the structure.

Detailed cross sections of the reservoir pool were entered into the model for a reservoir reach. These cross sections define the reservoir storage to be routed downstream in the breach model.

Average breach width was estimated using Froehlich's regression equation (Froehlich 1995b). This method uses the equation

$$\overline{B} = 15 k_0 V_w^{0.32} H^{0.19} \quad (1)$$

where V_w is the reservoir volume at the time of failure (millions of m^3), H is the height of the final breach (meters), and k_o is equal to 1.4 for an overtopping failure mode or 1.0 for other failure modes. This equation provides an average breach width of 224 ft for Dullknife Reservoir.

Breach side slopes were assumed to be 1 to 1. This is the average slope that Froehlich (1995b) found in the analysis of 63 embankment dam failures.

A time-to-peak estimate was created using Froehlich's regression equation (Froehlich 1995b). This method uses the equation

$$t_f = 3.84 V_w^{0.53} h_b^{-0.90} \quad (2)$$

where t_f is the breach formation time (hours), V_w = is the reservoir volume at time of failure (millons of m^3) and h_b is the height of breach (m). This method provides a time-to-peak estimate of 0.61 hours.

Table 1: Breach characteristics, Dullknife Reservoir.

Breach Shape				Water	Time		
Average Width (ft)	Bottom Width (ft)	Sideslope (ft/ft)	Height (ft)	Surface Elevation (ft)	to Peak (hrs)	Volume (ac-ft)	Peak Flow (cfs)
224	150	1/1	74	8152	0.61	5100	160,000

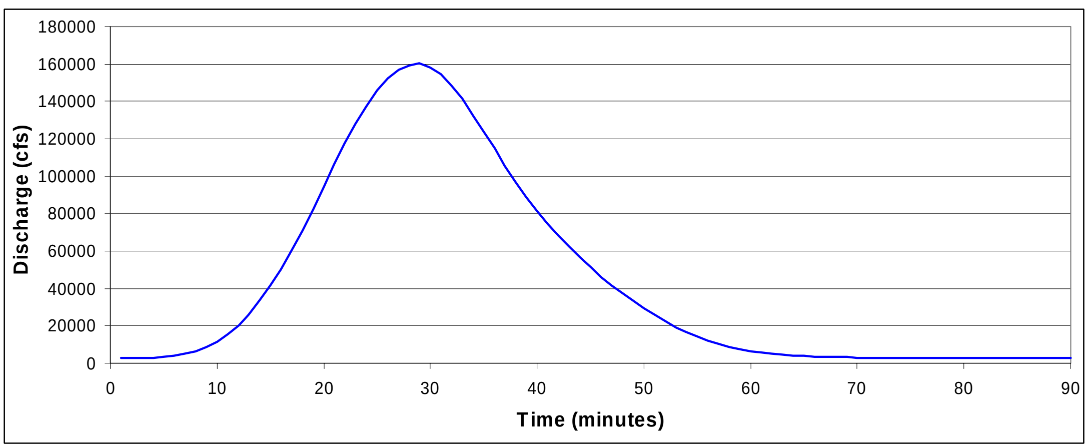


Figure 7: Initial breach hydrograph.

To verify the appropriateness of the HEC-RAS predicted peak breach flow, the estimate was compared to results generated from numerous predictor equations.

First, the regression equation developed by Dave Froehlich (Froehlich, 1995a) was used to estimate the peak flow expected by a breach of Dullknife Reservoir. This well-documented peer reviewed equation, which was developed from 22 embankment dam failures and has a R^2 of 0.934, is

$$Q_p = 0.607 V_w^{0.295} H_w^{1.24} \quad (3)$$

where V_w is the reservoir volume at time of failure (m^3) and H_w is the height of water in the reservoir at the time of failure above the final bottom elevation of the breach (m). With an embankment height of 74 ft (22.6 m – to floodplain level) and storage at crest of approximately 5100 ac-ft (6,284,000 m^3), a peak discharge of 103,000 cfs was estimated.

Peak flow estimates were also computed using the lesser-documented equations developed by NRCS. In accordance with the NRCS TR-60 1990 addendum, the criteria for peak flow prediction for an embankment height less than 103 ft is

$$Q_{max} = 1100 B_r^{1.35} \quad (4)$$

where

$$B_r = \frac{V_s H_w}{A} \quad (5)$$

But the peak flow is not to be less than

$$Q_{max} = 3.2 H_w^{2.5} \quad (6)$$

and need not exceed

$$Q_{max} = 65 H_w^{1.85} \quad (7)$$

where V_s is the reservoir storage at the time of failure (ac-ft), H_w is depth of water at dam at time of failure (ft) and A is cross-section area at dam at location of breach (ft^2). With an embankment cross-sectional area of 30,270 ft^2, results for all methods are provided in Table 2.

Table 2: Breach hydrograph characteristics.

Description	Reservoir WSEL (ft)	Reservoir Volume (ac-ft)	HEC-RAS Peak (cfs)	Froehlich Peak (cfs)	NRCS Peak Estimates		
					Eq. 4 (cfs)	Eq. 6 (cfs)	Eq. 7 (cfs)
at Embankment Crest	8152.0	5,100	160,000	103,000	33,100	151,000	187,000

The peak flow of 160,000 cfs is significantly larger than the Froehlich equation's result of 103,000 cfs but within the range of NRCS's TR-60 criteria – the HEC-RAS breach wave prediction is considered reasonable.

Since an overtopping event is being modeled in this analysis, a large hydrologic event is assumed to occur within the reservoir's watershed, an event large enough to completely fill the reservoir to the capacity of the emergency spillway. However, in the breach routing no adjacent watersheds (to the downstream reaches) are assumed to be contributing flow to the North Fork of the Powder River. **Hence, this analysis predicts the maximum likely inundation due only to a breach of Dullknife reservoir's embankment.**

HYDROGRAPH ROUTING

The Hydrologic Engineering Center – River Analysis System (HEC-RAS) one-dimensional (1-D) computer program, by the U.S. Army Corps of Engineers, was used to route the floodwave from the dam breach through the river valley of the North Fork of the Powder River. HEC-RAS version 3.1.2 was used in this analysis.

Computation Methodology

To support the basis of the modeling used in this dam breach analysis and to discourage a "black box" mentality, the basic equations used in these computations are briefly presented.

The physical laws that govern unsteady flow modeling, as presented in the HEC-RAS Hydraulic Reference Manual (Brunner and Goodwell, 2002), are conservation of mass (the continuity equation) and conservation of momentum. The general continuity equation (not separately written for both the channel and floodplain) is:

$$\frac{\partial A}{\partial t} + \frac{\partial S}{\partial t} + \frac{\partial Q}{\partial x} - q_1 = 0$$

Where: ∂ = partial differential.
A = cross-sectional area.
t = time.
S = storage from non conveying portions of cross section.
Q = flow.
x = distance along the channel.
q_l = lateral inflow per unit distance.

The momentum equation can be stated as "the net rate of momentum entering the volume (momentum flux) plus the sum of all external forces acting on the volume be equal to the rate of accumulation of momentum" (Brunner and Goodwell, 2002). In differential form, it is:

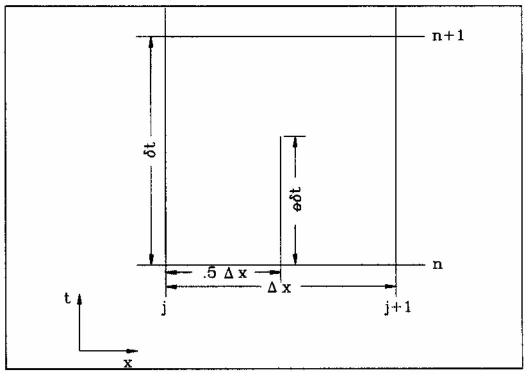
$$\frac{\partial Q}{\partial t} + \frac{\partial QV}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0$$

$$S_f = \frac{Q|Q|n^2}{2.208R^{4/3}A^2}$$

Where: V = velocity
g = acceleration due to gravity.
$\frac{\partial z}{\partial x}$ = water surface slope.
S_f = friction slope.
n = Manning's roughness estimate.
R = hydraulic radius = area/wetted perimeter.

The most successful and accepted procedure for approximating solutions to the non-linear unsteady flow equations is with a four-point implicit solution scheme, also known as a box scheme (Brunner and Goodwell, 2002). The HEC-RAS Hydraulic Reference Manual describes this as follows:

> *Under this scheme, space derivatives and function values are evaluated at an interior point,* $(n+\theta)\Delta t$*. Thus values at* $(n+1)\Delta t$ *enter into all terms in the equations. For a reach of a river, a system of simultaneous equations results. The simultaneous solution is an important aspect of this scheme because it allows information from the entire reach to influence the solution at any one point Consequently, the time step can be significantly larger than with explicit numerical schemes.*



[Typical finite difference cell used in HEC-RAS computations (from Brunner and Goodwell, 2002).]

The general implicit finite difference forms are as follows:

The time derivative is approximated as: $\dfrac{\partial f}{\partial t} \approx \dfrac{\Delta f}{\Delta t} = \dfrac{0.5(\Delta f_{j+1} + \Delta f_j)}{\Delta t}$

The space derivative is approximated as: $\dfrac{\partial f}{\partial x} \approx \dfrac{\Delta f}{\Delta x} = \dfrac{(f_{j+1} - f_j) + \theta(\Delta f_{j+1} - \Delta f_j)}{\Delta x}$

The function value is: $f \approx \overline{f} = 0.5(f_j + f_{j+1}) + 0.5\theta(\Delta f_j + \Delta f_{j+1})$

Where: Δ = difference or change in.

Using this methodology, the finite difference form of the continuity equation used by HEC-RAS (which separates channel and floodplain flow) is:

$$\Delta Q + \frac{\Delta A_c}{\Delta t}\Delta x_c + \frac{\Delta A_f}{\Delta t}\Delta x_f + \frac{\Delta S}{\Delta t}\Delta x_f - \overline{Q_l} = 0$$

Where: c = channel.
f = floodplain.
$\overline{Q_l}$ = average lateral inflow.

Assuming a horizontal water surface across the cross section and perpendicular flow to the plane of the cross section, the finite difference form of the momentum equation is:

$$\frac{\Delta(Q_c \Delta x_c + Q_f \Delta x_f)}{\Delta t \Delta x_e} + \frac{\Delta(\beta VQ)}{\Delta x_e} + g\bar{A}\left(\frac{\Delta z}{\Delta x_e} + \overline{S_f} + \overline{S_h}\right) = \xi \frac{Q_l V_l}{\Delta x_e}$$

Where: Δx_e = equivalent flow path

$\Delta(\beta VQ) = \Delta(V_c Q_c) + \Delta(V_f Q_f)$

S_f = frictional slope for the entire cross section.

S_h = local frictional slope, from bridge piers, navigation dams, cofferdams, ect.

Q_l = lateral inflow.

V_l = average velocity of lateral inflow.

ξ = fraction of momentum entering a receiving stream.

If the implicit finite difference solution scheme is applied directly to these non-linear equations, a series of non-linear algebraic equations result. To avoid the resulting slow and unstable iteration solution schemes, these equations are linearized for their use in HEC-RAS (Brunner and Goodwell, 2002).

For a more comprehensive presentation of the solution equations and techniques used in HEC-RAS, please see the HEC-RAS Hydraulic Reference Manual.

Roughness Estimates for Steep Reaches

Dam breaches and other flow events of such extreme intensity can have profound effects upon channel and valley morphology for alluvial streams. During such extreme flows the steep wooded stream channels and floodplains prevalent in mountainous areas can be stripped of woody material and alluvial beds may be scoured and mobilized. This may produce a cascading debris flow. A debris flow is a type of mudflow with a prevalence of large material (larger than sand-sized) mixed with fines and water.

In unsteady modeling, the typical methods and guides for predicting Manning roughness (*n*) values by inspection, such as those provided in Chow (1959), Arcement & Schneider (1989), Brunner & Goodell (2002), though sufficient for many situations, are oftentimes not adequate for high gradient streams (Trieste 1994). This is especially the case during extreme events, since current conditions likely don't reflect the prediction conditions. The energy loss in hydraulic jumps, turbulence, and obstructions are not adequately incorporated in these *n* estimates. The great deal of bed material and debris liberation and movement that is expected during very high flows further increases the uncertainty in *n* since existing flow conditions and roughness are not equivalent to extreme flow conditions and roughness. The very high Froude numbers and velocities often computed during modeling of high flows on steep gradient streams indicate the problem with the roughness estimates.

Breach Case Study

The catastrophic breach of the Lawn Lake embankment dam, a 26 ft high embankment dam located in Rocky Mountain National Park, illustrate the problems often encountered in modeling unsteady flow from breaches in mountainous terrain. As described in Jarrett and Costa (1984), the catastrophic breach occurred on July 15, 1982 from a piping failure. The failure released 674 ac-ft of water, with an estimated time-to-peak flow of 10 minutes and an estimated peak discharge of 18,000 ft^3/s. The breach wave occurred over slopes from 5 to 25 percent in the canyon of the Roaring River, 0.7 percent in

Horseshoe Park, and up to 8 percent in the Fall River above the town of Estes Park and the Big Thompson River. The breach created a flood wave in the Roaring River that was characterized by eyewitnesses as a "wall of water" 20 to 30 ft high. The leading edge of the wave was not likely to have been a vertical wall of water but the peak was likely to have been very close to the wave front, which would have been accentuated by the mass of entrained debris. Besides the mass of alluvium mobilized on the Roaring River reach, the flood wave consisted of a mass of vegetation mobilized from the valley over a wide swath, from 70 to 500 ft wide. The leading edge, due to all of the debris, moved much slower than expected for a steep channel. Flow likely alternated from supercritical for short reaches to subcritical behind temporary debris dams that formed, and again as supercritical flow for a short reach as the dam breached and until the next dam formed (Jarrett and Costa, 1984).

An unsteady flow model was developed by Jarrett and Costa (1984) for the breach analysis, in an attempt to match the model to actual conditions. The model used an initial *n* estimate of 0.125 and a calibrated value 0.200. Velocity estimates ranged from 3.3 to 12.6 ft/s. Maximum flow depths ranged from 6.4 to 23.8 ft and maximum flow widths ranged from 97 to 1112 ft. Flood peaks from the Lawn Lake dam failure, depending upon the reach, were 2.1 to 30 times the 500-year flood magnitude (Jarrett and Costa, 1984).

The geomorphic effects of this breach were significant. On the Roaring River channels were widened tens of feet, locally scouring 5 to 50 ft with the valley alternately scoured and filled, depending upon valley slope. At the mouth of the Roaring Fork, at Horseshoe Park, a 365,000 cubic yard alluvial fan was deposited. The largest boulder known to be moved during the event is 14x17.5x21 ft (Jarrett and Costa, 1984).

According to Jarrett and Costa (1984), the Lawn Lake breach analysis indicates that to more appropriately model a breach flow through steep, moveable bed, debris saturated stream valleys, Manning *n* estimates need to reflect a flow with entrained debris, with bed scouring and deposition, instead of existing conditions. This was the reason for the need to calibrate *n* to the value of 0.200.

Conclusions regarding the appropriateness of modeling flow of such flow events as supercritical have been reached in other breaches in steep terrain. For example, a hydraulic analysis performed on the Quail Creek Dike Failure flood in Utah, which flowed for the first 1.6 km (1 mile) through a steep (0.032 m/m) slope drainage, showed that the model depths could not match the actual field depths unless the reach was modeled as being entirely subcritical (Trieste 1992).

Supercritical vs. Subcritical Flows in Natural Channels

Analysts often model high flows on steep reaches as supercritical flow. This assumption can be valid for rigid boundary channels, such as concrete or bedrock channels, but is a questionable practice for the natural alluvial channels typically modeled (Trieste 1994).

For cobble and boulder bed high-gradient streams with extreme flows, Jarrett (1984) suggests that a limiting assumption of critical depth in subsequent hydraulic analyses appears to be reasonable. Trieste (1994) suggests that modeling supercritical flow for long reaches within the National Weather Service’s DAMBRK (Freud 1988) or its successor FLDWAV (Fread and Lewis, 1998) may be invalid except for possibly bedrock channels. For steep boulder and cobble-bed streams, high Froude numbers likely indicate that not all energy losses have been fully accounted for (Jarrett 1987).

Critical Depth Assumption

Grant (1997) asserts that in steep (slope greater than 1%) mobile-bed channels, interactions between hydraulics and bed configurations prevent the Froude number from exceeding 1 for more than short distances and time periods. The Froude number is defined as

$$Fr = \frac{\alpha^{0.5} v}{(gd)^{0.5}} \qquad (3)$$

where *Fr* is the Froude Number, α is the kinetic energy correction factor, *v* is velocity, *g* is acceleration due to gravity, and *d* is flow depth. The Froude number equals 1 at critical flow, is greater than 1 for supercritical flow, and is less than 1 for subcritical flow. At critical flow, specific energy is minimized, hence maximizing discharge per unit width – critical flow is highly efficient.

Critical flow in steep channels is maintained by the interaction of the mobilized bed and vegetation with the water surface at high Froude numbers, resulting in the oscillating creation and destruction of bed forms. This has been shown in field observations of sand-bed streams, active braided rivers, step-pool streams, laboratory rills, lahar runout channels and some bedrock channels (Grant 1997). Empirical analysis of mobile bed streams indicate that competent (with bed load transport) flows tend to asymptotically approach critical flow. In sand bed streams, Grant found that the Froude number oscillated between 0.7 and 1.3, with and average of 1.0 in the thalweg. He asserts that critical flow represents a point of high efficiency in flow, beyond which turbulence (hydraulic jumps) interact with bed materials, resulting in rapid energy dissipation and a return to near critical flow (Grant, 1997).

Assuming critical flow in the modeling of flow hydraulics during extreme events in steep, mobile bed streams may likely be an accurate and appropriate method for modeling flow in steep channels. In any case, it is indicated that a critical depth assumption is more appropriate than assuming current roughness values for dam breach modeling in alluvial-bed streams.

This technique has been adopted for certain applications. Since an assumption of supercritical flow was made in many indirect measurements of peak flow using the slope-area method, many high outliers can be found in gage records for steep streams. These estimates may be significantly overestimated (Jarrett 1987, Webb and Jarrett 2002). A critical depth method is now preferred by many practitioners in such situations. The critical depth technique is also being used in paleoflood studies, as discussed in Webb and Jarrett (2002).

Hence, it is believed by many hydrologic practitioners that supercritical flow is not usually sustainable for significant distances in steep erodable-bed channels but that critical flow is common in streams with slopes greater than about 1 percent (Webb & Jarrett, 2002; Grant 1997). Supercritical flow is usually only sustained in steep, hydraulically smooth, rigid channels, such as concrete channels. Knowing this, it would be best to use a critical depth methodology within an unsteady flow model, but such a feature has yet to occur within FLDWAV or HEC-RAS. In the meantime, a quasi-calibration can be performed on Manning's *n*, to adjust it to prevent supercritical flow for more than short distances and time periods.

Calibration using Froude Number

This issue of the selection of the appropriate steep-channel n values within this analysis is relevant in the Canyon reach of the North Fork of the Powder River, from Dullknife dam to the mouth of the canyon at the Hat Ranch. Two segments of this reach were visited (Figures 8 through 11) to assess, among other things, the bed characteristics of the channels. At issue is whether the stream should be considered a bedrock or alluvial-bed stream. The upper segment indicated a large amount of woody vegetation, patchy bedrock bed but principally alluvial bed characteristics. The lower segment at the canyon mouth was an alluvial-bed stream.

Figure 8: Alluvial bed, upper canyon reach.

Figure 9: Bedrock channel, canyon reach.

Figure 10: Alluvial bed, near mouth of canyon.

Figure 11: Alluvial bed, at streamgage near mouth of canyon

Due to difficult and time-consuming access, the entire canyon was not visited in this study and the extent of bedrock channel within the entire canyon is not known. However, considering the alluvial dominant bed form of the visited segments and the ready availability of vegetation as a source of debris, the reach is on average considered to be a steep, mobile-bed stream and its roughness values have been adjusted accordingly.

To more appropriately model dam breach travel times, velocities, depths, widths, and attenuation, Manning's *n* values have been adjusted in the Dullknife breach analysis analysis to prevent the simulation of supercritical flow for all but the shortest reach lengths. For steep reaches (stream segments that produce Froude numbers greater than 1.0 using ordinary methods), the following procedure was used in the selection of *n* values in this dam breach analysis:

First, *n* values were chosen using visual inspection and the recommendations of Chow (1959) and Brunner & Goodell, 2002. This initial model was developed for the steeper reaches, to the point where the profile significantly flattens out and critical or supercritical flow was no longer expected.

The results were then inspected, looking for, besides the usual warning and errors that would need to be corrected, high Froude numbers in the computed model. If the Froude number at the modeled cross-sections was typically greater than 1.0 (and above 1.2 to 1.3 at any particular section) the roughness estimates (*n*) for the affected cross-sections were increased and an additional model run performed. If the Froude numbers for the revised model didn't fall within the expected range (below 1.2 to 1.3 but above 0.8 for sections that were previously computed as supercritical) this process was repeated in a trial-and-error manner until Froude numbers all fell below 1.3, with an average of 1.0 for the affected sections. Such a method likely provides more realistic estimates of velocity and travel time for a dam-breach flood wave through the steep canyon reach of the North Fork Powder River.

LIDAR and Ortho-Imagery Data Use

Dam breach analyses performed to assess the extent of potential impacts to downstream property, resources and ecosystems require the use of many cross-sections. These cross-sections are required to be close enough to effectively represent the varying morphology (shape) and roughness of the river valley. However, the extensive funds for surveying so many cross-sections are not typically available - the analyst must often rely on the contours from USGS 7.5-minute quadrangles, usually at 20 or 40-ft intervals. This data must be entered either manually (a time-consuming task) or through the use of 30- or 10-meter grid data (a DEM – Digital Elevation Model) that was interpolated from these topographical maps. In both cases these methods will often not show the complete shape of the valley and, hence, not model attenuation properly. In addition, many of these topographical maps are quite old, often dating back thirty to fifty years – often they don't represent the present-day stream morphology. Inundation mapping created from such sparse data will likely cause some structures to be inappropriately included within inundation zones, or worse, excluding them from the true inundation zones and possibly endangering lives in the case of a breach.

The Dullknife dam breach analysis was performed with the benefit of 1.2-meter horizontal resolution, 15-cm vertical accuracy LIDAR (LIght Detection And Ranging) elevation data. With the use of a GIS-modeling interface, such as the Hydrologic

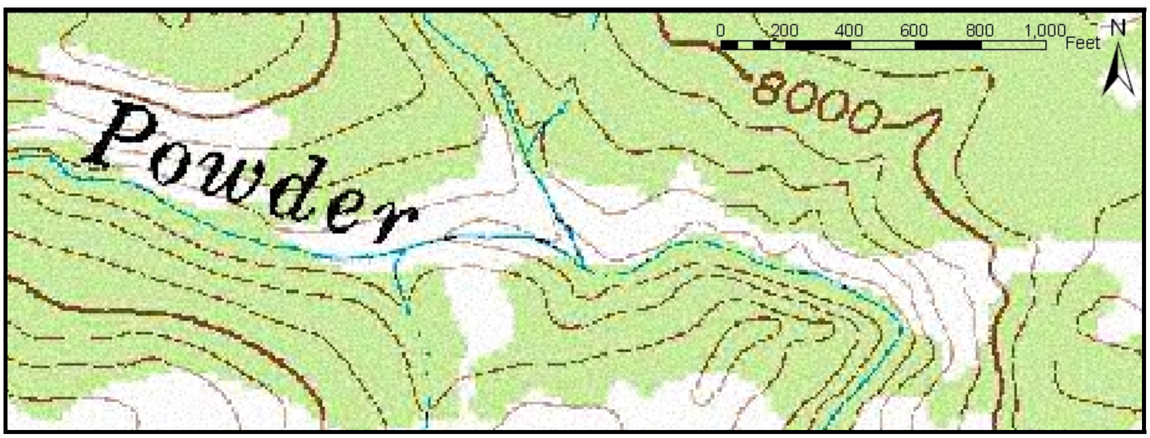


Figure 12: 7.5 minute quadrangle image for a short stretch of the N. F. Powder River.

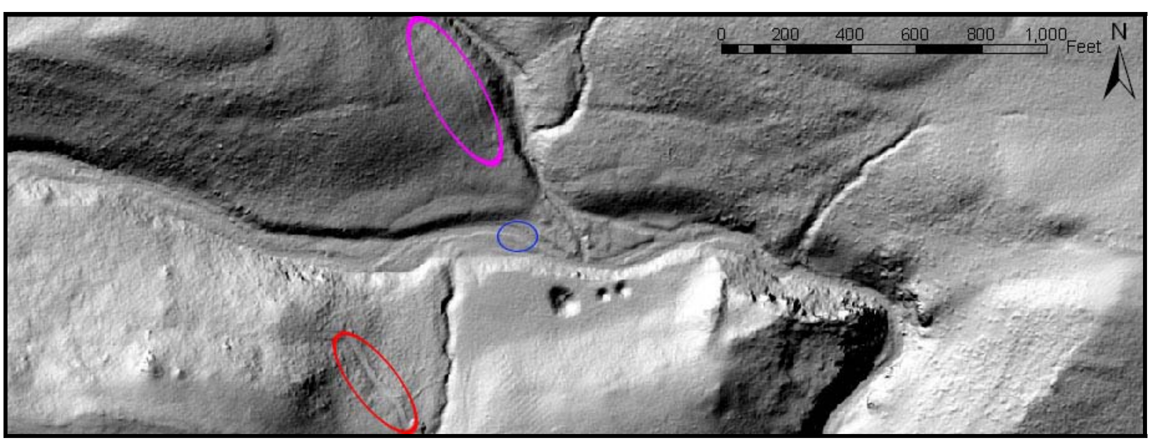


Figure 13: Shaded relief image of same area as Figure 12, from 1-meter LIDAR.

Engineering Center's GeoRAS, this data allows the construction of a better, current, and more accurate model over less time.

The paired Figures 12 and 13 have been provided to illustrate the much greater level and accuracy of detail available from 1-meter LIDAR data compared to 7.5-minute quadrangle topography maps. In Figure 13 note the logging road entering the image from the South (red ellipse), just to the left of the incoming drainage, as well as the faint but visible jeep trail entering the image from the North (violet ellipse), immediately to the left of incoming Bull Creek. This trail, which is only faintly visible on the ground, serviced a streamgage (Figure 14) that used to be operated at the confluence of Bull Creek with the N.F. Powder River. Individual boulders and rock outcrops are readily apparent throughout the image as well as the stream channel. This stream channel (blue ellipse), as shown in Figure 15, is fairly small, indicating that the LIDAR data can readily identify some stream morphology features in even relatively small streams.

Figure 14: Abandoned streamgage just downstream of Bull Creek.

Figure 15: Stream channel just upstream of the Bull Creek confluence.

Figure 16 is an image of LIDAR-based 40-foot (solid) and 20-foot (dotted) contours superimposed upon a 7.5-minute quadrangle image with 40-foot contours. Note that the quadrangle contours do, in general, follow the contours of the LIDAR data but the details differ: Hillsides have different shapes; stream valleys have different widths; and tributaries enter the river at different locations. This is not unexpected – 7.5 minute quadrangles were not intended to define stream morphology at the level usually needed to properly model stream hydraulics.

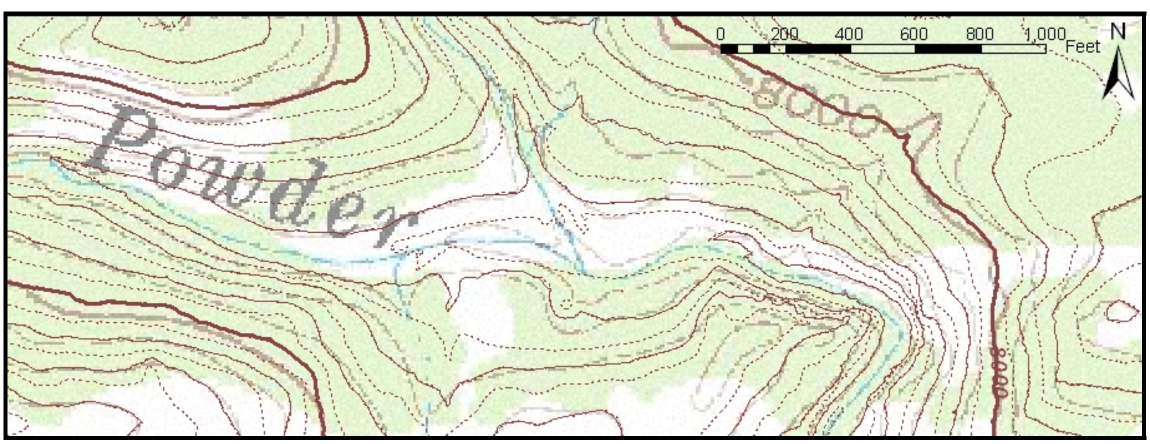
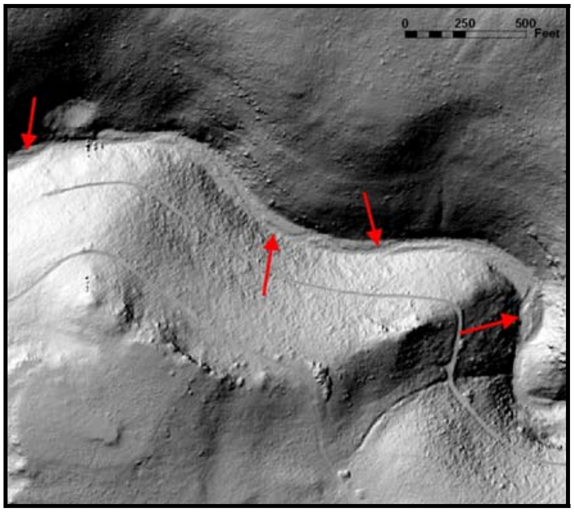


Figure 16: LIDAR based 40-foot (solid) and 20-foot (dotted) contours superimposed upon 7.5-minute quadrangle image with 40-foot contours.



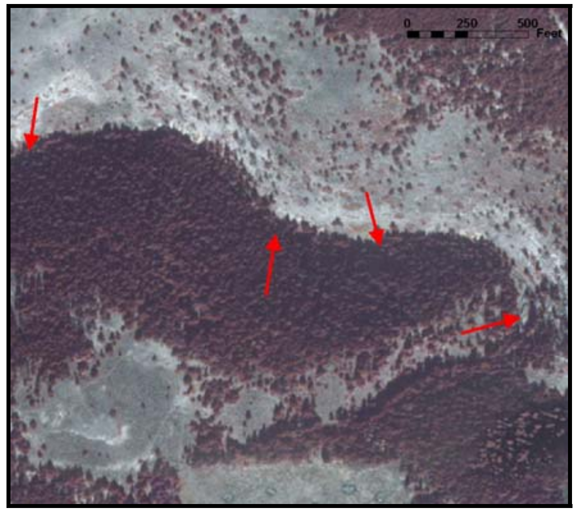
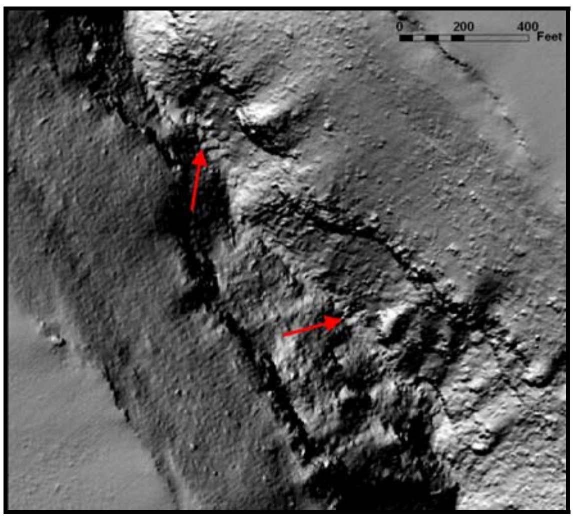


Figure 17: LIDAR shaded relief. Arrows indicate alluvial morphology.

Figure 18: 1-meter color aerial of same area as Figure 17.



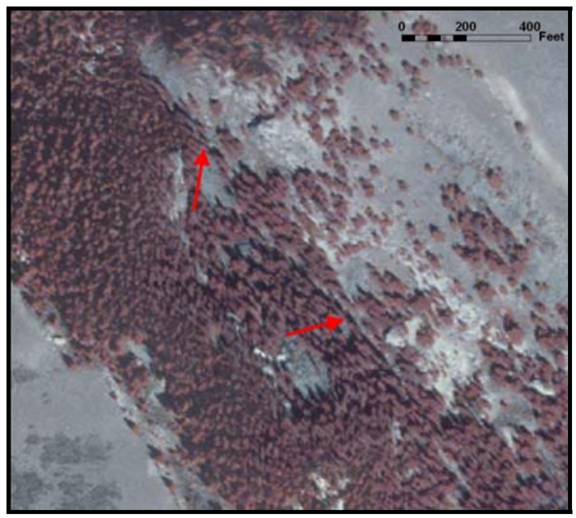


Figure 19: LIDAR shaded relief. Arrows indicate step-pool morphology.

Figure 20: 1-meter color aerial of same area as Figure 19.

Figures 17 though 20 are paired figures provided to illustrate the usefulness of using LIDAR in channel roughness (Manning's *n*) estimation. The upper paired figures are for identical areas, with the left image featuring LIDAR based shaded relief and the right image featuring 1-meter color infrared. In the photograph the bed features are obscured by trees while alluvial morphology is evident in the shaded relief (as is also the case in Figure 13). The lower paired figures show the same side-by-side shaded relief and color aerials, but feature step-pool morphology in the stream channel. This distinction is important – it has been used as a basis of varying Manning's *n* from 0.04 or 0.05 to 0.07 for the stream channel, leading to significant improvement in the model.

Also to be noted in Figure 17 are two logging roads clearly visible in the shaded relief.

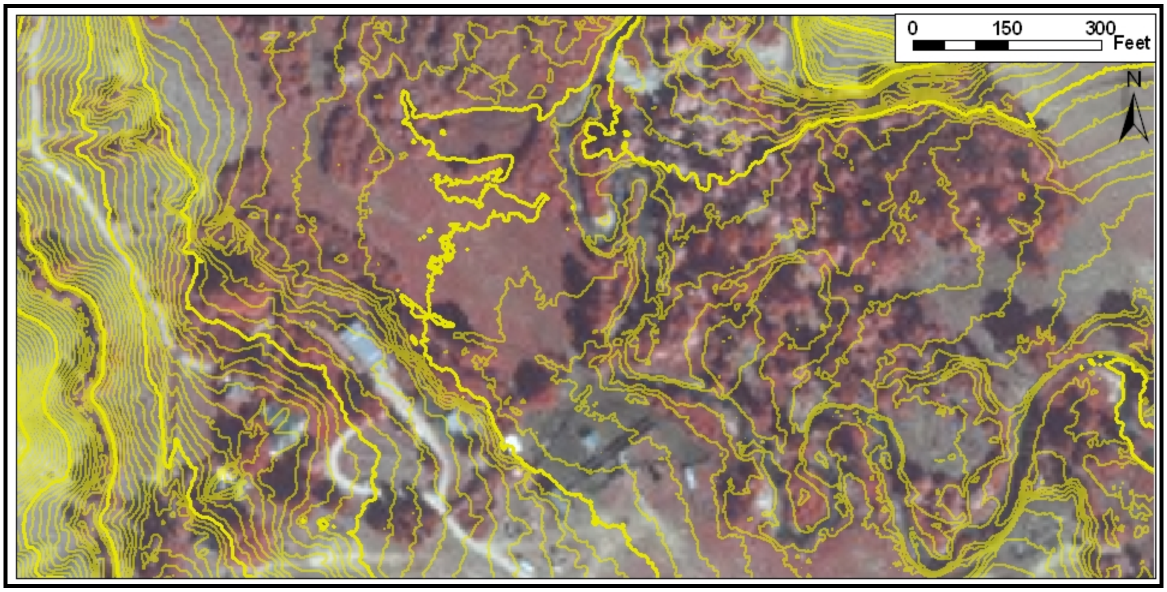


Figure 21: Hat Ranch – color infrared aerial image with 2-ft LIDAR-based contours.

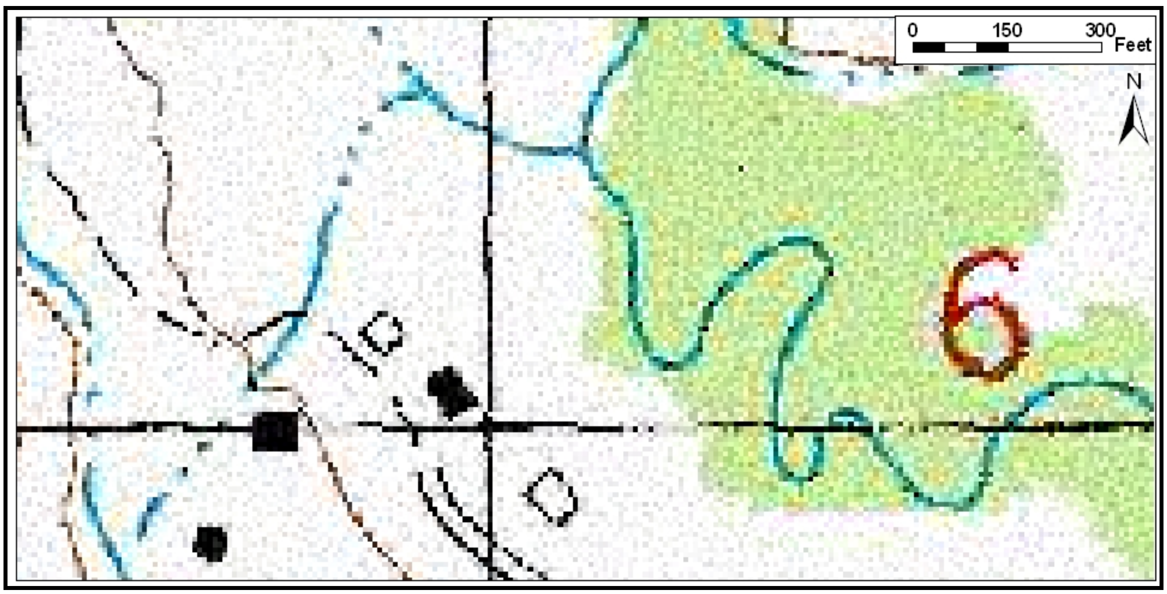


Figure 22: Hat Ranch – standard 7.5 minute USGS quadrangle, identical area as Figure 21.

USGS 7.5-minute quadrangle maps have very limited data available to extract geometry for cross-section development and inundation extent delineation. As an example, Figures 21 and 22 illustrate a portion of floodplain modeled in the Dullknife dam breach analysis at the Hat Ranch with a typical 7.5 minute quadrangle map (lower) and LIDAR-based 2-ft contours on a 1-meter color-infrared image (upper). During typical analyses this quadrangle would have to be the source of cross-section data, since surveying 60 miles of stream valley at a frequency needed to quantify the variability of valley shape is not economically feasible. Such sparse data being used in inundation mapping may lead to questionable decisions regarding the extent of inundation from a breach. This significant problem is in addition to the poorer-quality modeling resulting from the coarse cross-sections developed from 7.5 minute quadrangle images, possibly leading to significant misestimates in floodwave attenuation and less accurate breach analyses and emergency action plans.

To illustrate the substantially different quality cross-sections developed from LIDAR-based and 7.5 minute quadrangle source data, Figure 23 has been developed. In this figure note the many more data points available from the LIDAR-based data, compared to the 7.5-minute quadrangle data. The LIDAR data uses 97 data points for the cross-section while the USGS quadrangle only provides 7 points. Also, the quadrangle data does not provide details on the stream channel, which is clearly evident in the LIDAR data – this inaccuracy may be significant to the accuracy of the model. Additionally, the flat form of the valley bottom is not as well defined in the 7.5-minute quadrangle data, which may lead to under-quantified attenuation estimates and structures further downstream in an analysis being inappropriately designated as impacted by a breach. Additionally, structures located at a point similar to this section may be incorrectly designated as outside an inundation zone, a significantly undesirable condition that could lead to loss of life. Finally, it is interesting to note the approximately 8-foot difference in valley bottom elevation between the two types of data. It is unknown at this time the source of this inconsistency. The existence of this difference should be kept in mind when using the output elevations from this report, specifically the estimated maximum water-surface and energy elevations.

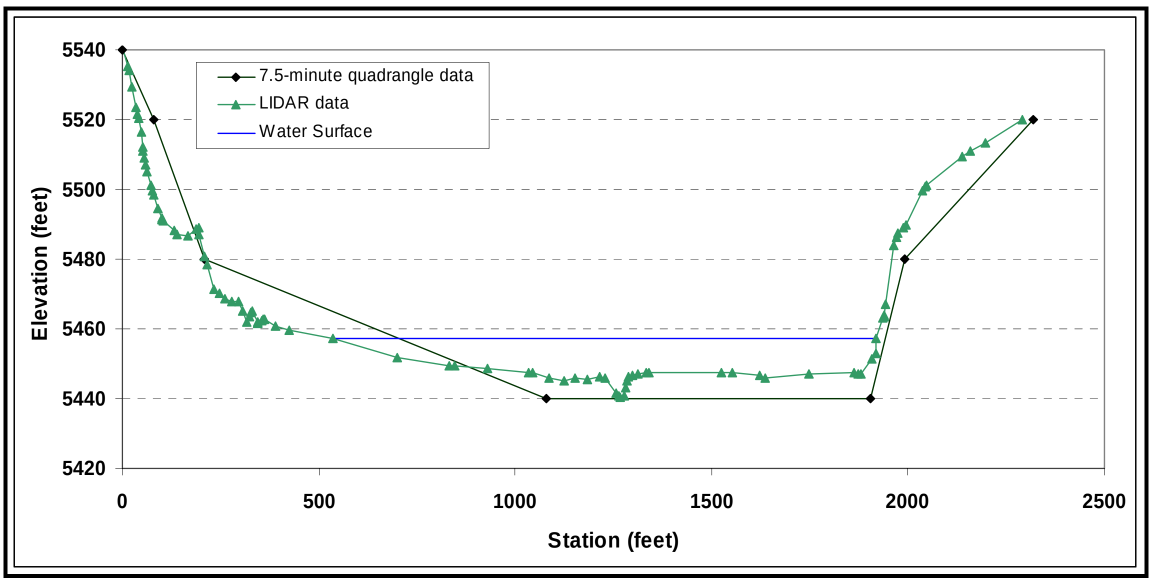


Figure 23: Cross-section 891476, downstream of the Hat Ranch. Both 7.5-minute quadrangle based and LIDAR based cross-sections are provided for comparison.

The LIDAR-based cross-sections have been developed for the Dullknife breach analysis using 0.5 meter z-value TINs with HEC GeoRAS, an extension for ArcView 3.x. The computationally-intensively created TINs were first created in ArcToolbox 8.3, which was then used in GeoRAS. Figure 24 has been provided to illustrate a TIN for a small portion of the stream valley at section 891476. A LIDAR-based shaded relief image of the same area has also been provided in Figure 25.

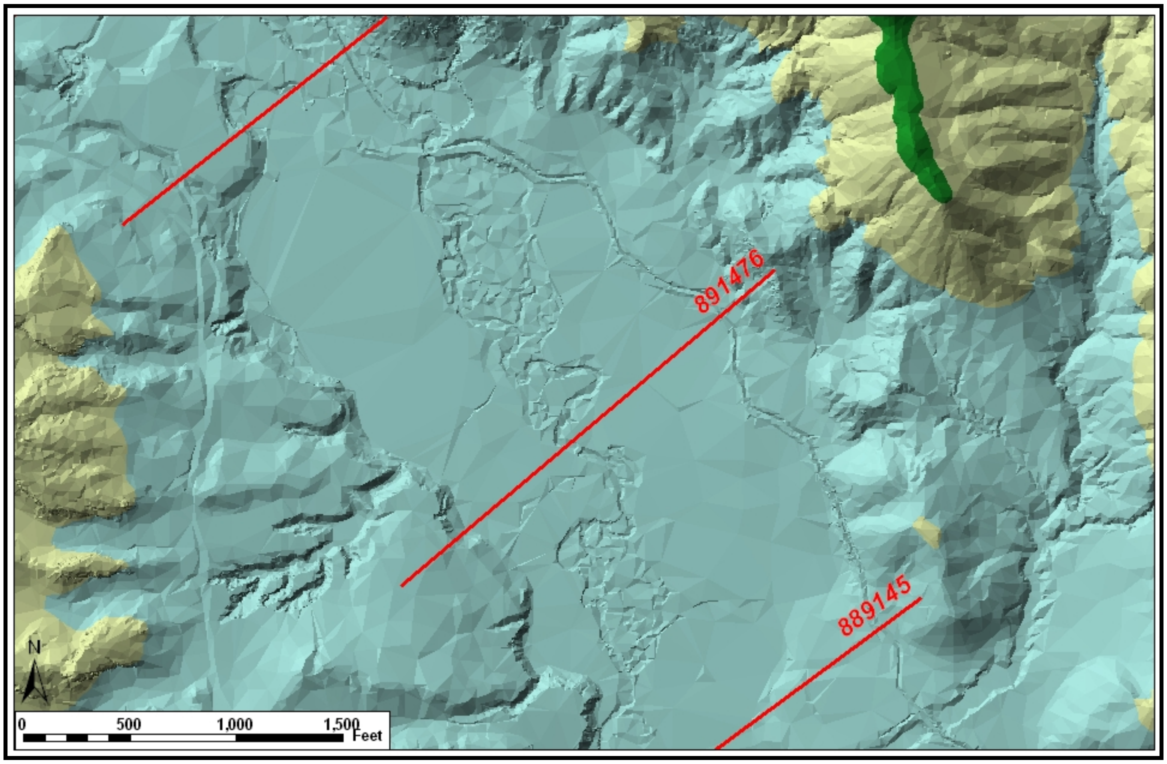


Figure 24: LIDAR-based 0.5-meter TIN, at section 891470.

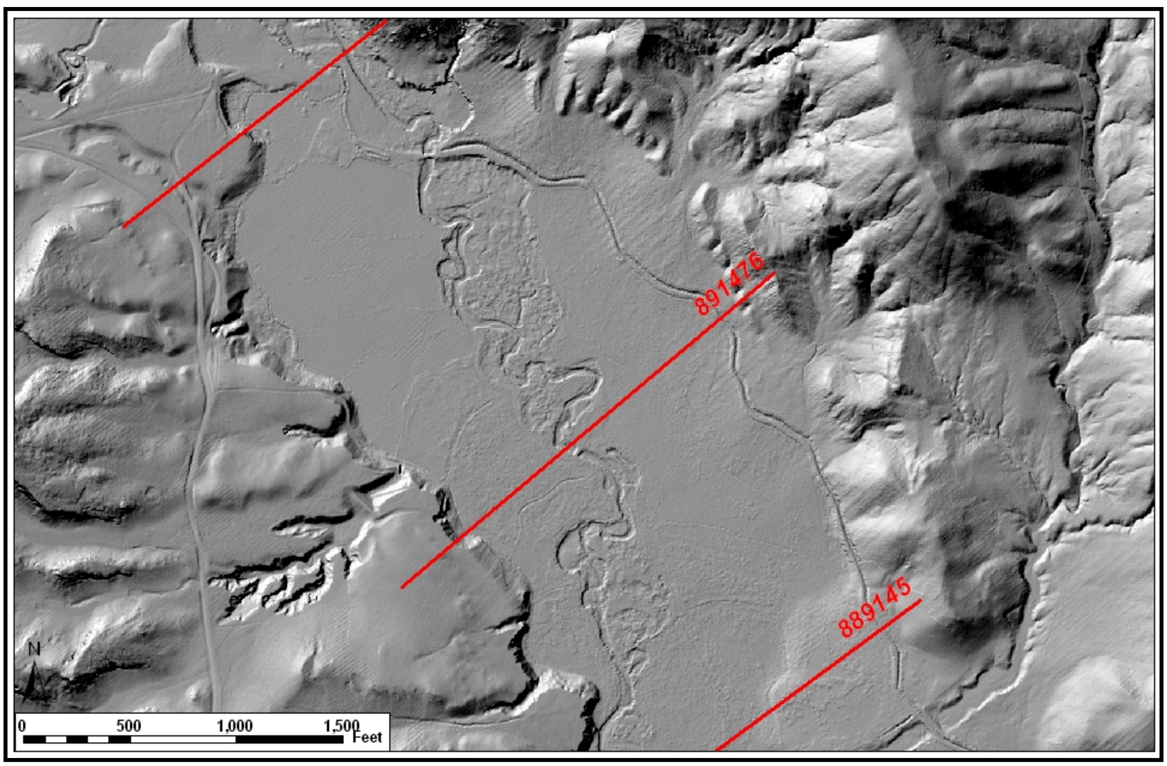


Figure 25: LIDAR-based 0.5-meter shaded relief, at section 891470.

In hydraulic analyses Manning's *n* (roughness) is often the most sensitive variable. However, the extensive model length of 58 valley miles in the Dullknife analysis prohibits visits to every cross-section, especially in difficult access areas. As a result this hydraulic analysis had a great deal to gain from remotely-sensed determination of *n*. This study has used color infrared imagery (with sampled ground verification) to help determine *n*, to differentiate between types and density of vegetation with trees, shrubbery, irrigated cropland, and rangeland being distinctly visible. Figures 26 and 27 have been provided to show the power of this tool and to compare the much greater visibility of color infrared over black & white images. The color infrared images make this approach readily possible while the black & white images aren't sufficient for this purpose.

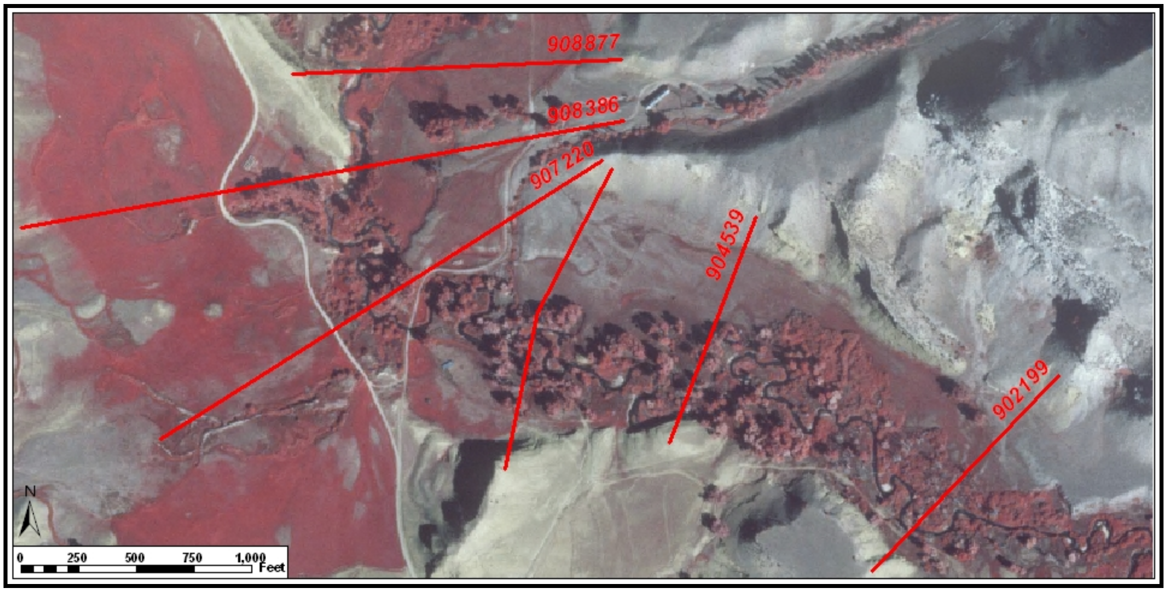


Figure 26: 1-meter color infrared image used for roughness determination.

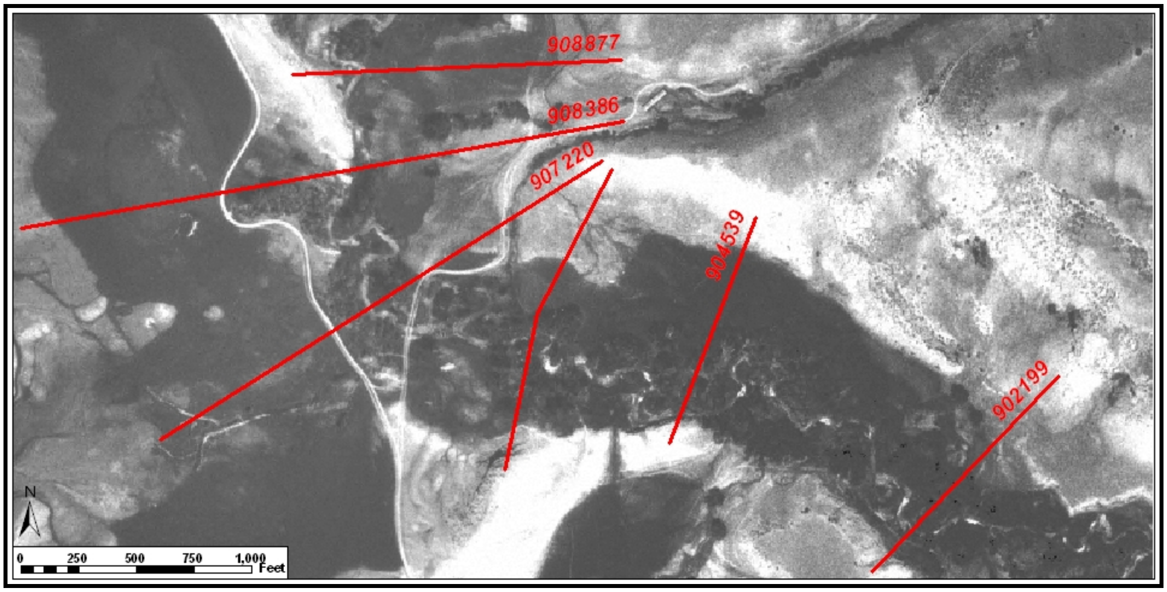


Figure 27: Black & white image of same area, showing poor vegetative contrast.

Modeled Reaches

To assist in model debugging, the floodwave routing was performed in five linked but separate analyses. These model reaches were Dullknife Reservoir; North Fork Powder River, Canyon; North Fork Powder River, Canyon to Rt. 191 Crossing; North Fork Powder River, Rt. 191 Crossing to the Powder River Confluence; and the Powder River from the North Fork Confluence to the Hoe Ranch. The entire model length is illustrated in the plan and profiles of Figures 28 and 29.

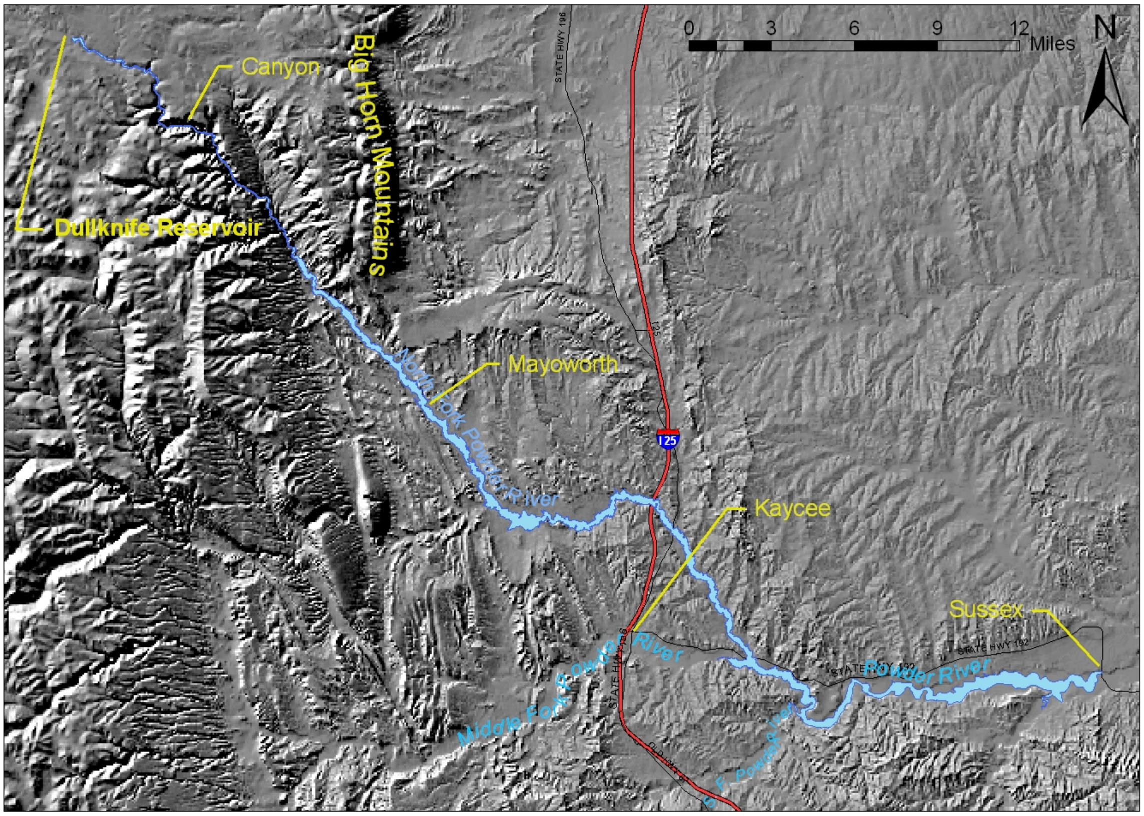


Figure 28: Plan view of the Dullknife breach analysis.

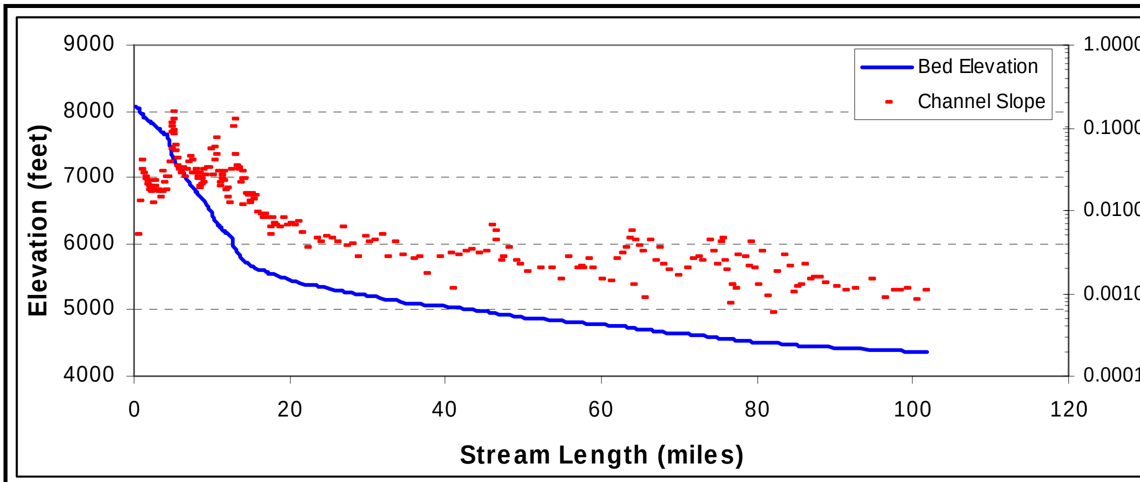


Figure 29: Profile view of Dullknife breach analysis.

North Fork Powder River, Canyon

Figures 8 through 11 in the previous sections document general reach characteristics. Cross-sections were developed using a 0.5 m TIN generated from a 1-m LIDAR-based DEM. For this 14.5-miles stream-length reach (13.9 miles valley-length) low-sinuosity stream (1.0 to 1.2), 103 cross-sections were generated. For computational stability, additional cross-sections were interpolated, with a spacing of 20 feet for a total of 3870 cross-sections.

Channel widths were determined through a combination of color infrared aerial photo measurement, cross-sectional geometry and shaded-relief imagery.

In the canyon, an *n* of 0.05 (cobbles, with large boulders) to 0.07 (boulder-dominated stream) was initially used for the stream, and 0.07 (light to medium brush and trees), 0.10 (medium to dense brush and trees), or 0.15 (dense trees, with flow into branches) was used for the floodplain. In parks and some other clearer areas, an initial channel n of 0.04 was used (gravels, cobbles and a few boulders), with 0.05 (scattered brush, heavy weeds), 0.07 (light to medium brush and trees), or 0.10 (medium to dense brush) was used in the floodplain. The horizontal variation in *n* option was used when n varied a great deal over the section. The assignment of *n* was determined through use of 1-meter color infrared imagery, shaded relief from the 1-meter LIDAR-based DEM, and field photographs.

Normal depth was assumed as the downstream boundary condition in this model, with a slope of 0.012, measured from a 2 meter contour interval created using the 1 meter LIDAR DEM.

The initial HEC-RAS model for this reach predicted a flood wave with sustained supercritical flow, with channel velocities as high as 98 ft/s and with Froude numbers as high as 2.8. From the above literature search, it is evident that these high values are not likely for a mobile-bed stream. Accordingly, Manning's *n* values for channel portions of cross sections were individually calibrated to maintain a Froude number between 0.9 and 1.2 for reaches where supercritical flow was initially indicated.

North Fork Powder River, Canyon to Rt. 191 Crossing

Figures 30 through 32 as well as Figures 21 through 27 (in the LIDAR section) document general reach characteristics. Cross-sections were developed using a 0.5 m TIN generated from a 1-meter LIDAR-based DEM. For this 32.3-mile stream-length (14.5 miles valley-length) low- to high-sinuosity stream (1.1 to 4.0), 61 cross-sections were generated. For computational stability, additional cross-sections were interpolated, with a spacing of 400 feet for a total of 459 cross-sections.

Channel widths were determined through a combination of color infrared aerial photo measurement, cross-sectional geometry from the DEM/TIN, and shaded-relief imagery.

In channels, an *n* of 0.040 was used (main channel that is clean, winding, with pools and shoals). In floodplains, *n* varied from 0.05 (scattered brush, heavy weeds), to 0.07 (light to medium brush and trees), to 0.10 (medium to dense brush and trees). When *n* varied across the floodplain, the horizontal variation in *n* option was used. The assignment of *n* was determined through use of 1-meter color infrared imagery and photograph-documented field visits.

Figure 30: Typical channel characteristics – upper portion of reach.

Figure 31: Typical channel characteristics – middle & lower portion of reach.

Figure 32: Typical valley conditions – Canyon to Rt. 191 reach.

Unconnected conveyance areas (such as from a side drainage entering the river) were treated as ineffective by using the ineffective flow option or by manually eliminating such areas from the cross-section.

Normal depth was assumed as the downstream boundary condition in this model, with a slope of 0.0093, measured from 20-foot contour interval created using the 1-meter LIDAR DEM.

Two bridges over the North Fork of the Powder River, specifically the Mayoworth Bridge and the WY Rt. 191 Bridge, exist on this reach and are shown in Figures 33 and 34. Both bridges have been modeled in this analysis. Ineffective flow areas were stipulated at both the adjacent upstream and downstream sections, for non-overtopping flows.

Two USGS streamgages have or currently exist near the upstream limit of this reach. A historic gage, *North Fork Powder River near Mayoworth* (06311500), with a watershed area of 106 mi^2, was operated by the U.S. Geological Survey (USGS) from 1941 to 1973 (33 years). This gage, once located near the Hat Ranch's main buildings, measured

Figure 33: Mayoworth Bridge over the N. F. of the Powder River.

Figure 34: WY Rt 191 bridge of the N. F. of the Powder River.

annual peak flows that ranged from 139 cfs to 1270 cfs (on 6/22/1959 and 8/11/1941, respectively) and has an associated log-Pearson based 100-year flow of 1500 cfs. A currently operated gage, located at the mouth of the canyon and named *N.F. Powder River Below Pass Creek, nr Mayoworth* (06311400), with a watershed area of 100 mi^2, has been operated by the USGS from 1979 to current (25 years). This gage measured annual peak flows ranging from 91 cfs to 1590 cfs (on 5/19/1989 and 8/1/1984, respectively) and has an associated log-Pearson based 100-year flow of 2820 cfs.

North Fork Powder River, RT 191 Crossing to Confluence

Figures 35 and 36 document general reach characteristics. Cross-sections were developed using a 0.5 m TIN generated from a 1-meter LIDAR-based DEM. For this 32.5-mile stream-length (14.2 miles valley-length) low- to high-sinuosity stream (1.1 to 5.3), 66 cross-sections were generated. For computational stability, additional cross-sections were interpolated, with a spacing of 100 to 400 feet for a total of 609 cross-sections.

Figure 35: Typical stream valley conditions – Rt. 191 Crossing to Confluence.

Channel widths were determined through a combination of color infrared aerial photo measurement, cross-sectional geometry from the DEM/TIN, and shaded-relief imagery.

In channels, an *n* of 0.040 was used (main channel that is clean, winding, with pools and shoals). In floodplains, *n* varied from 0.05 (scattered brush, heavy weeds) to 0.07 (light to medium brush and trees). When *n* varied across the floodplain, the horizontal variation in *n* option was used. The assignment of *n* was determined through use of 1-meter color infrared imagery and photograph-documented field visits.

Figure 36: Typical stream condition, Rt. 191 Crossing to Confluence.

Figure 37: I-25 bridge over the over the N. F. of the Powder River.

Figure 38: WY Rt. 196 bridge over the N. F. of the Powder River.

Figure 39: WY Rt. 192 bridge over the N. F. of the Powder River.

Normal depth was assumed as the downstream boundary condition in this model, with a slope of 0.0025, measured from 5-ft contour interval created using the 1 meter LIDAR DEM.

Three bridges over the North Fork of the Powder River exist on this reach (Figures 37 through 39), specifically I-25, WY Rt. 196 and WY Rt. 192. These structures are shown in Figures 37 through 39. These three bridges have all been modeled in this analysis.

Powder River, North Fork Confluence to Hoe Ranch

Figures 40 and 41 document general reach characteristics. Cross-sections were developed using a 0.5 m TIN generated from a 10-meter USGS DEM (LIDAR data was not gathered in this reach). Modeling was performed to the Hoe Ranch but flow was shown to attenuate to level sufficient to terminate the model by the community of Sussex.

For this portion of the reach, 28 cross-sections were generated for this 23.1-mile stream-length (14.5 miles valley-length) low- to high-sinuosity stream (1.0 to 2.6). For computational stability, additional cross-sections were interpolated, with a spacing of 600 feet for a total of 209 cross-sections.

Channel widths/bank locations measured from color infrared aerial photography and the DEM/TIN derived exported geometry.

Figure 40: Typical stream valley condition – Powder River reach.

Figure 41: Typical stream condition – Powder River reach.

The 10-meter DEM does not provide channel details, which is important to the analysis in this reach as the flow approaches in-channel capacities. To deal with this lack of detail, typical sections were used for each cross-section. This typical section was based upon LIDAR derived cross-sectional geometry for the Powder River upstream of the South Fork of the Powder River confluence.

In channels, an *n* of 0.040 was used (main channel that is clean, winding, with pools and shoals). In floodplains, *n* varied from 0.05 (scattered brush, heavy weeds) to 0.07 (light to medium brush and trees). When *n* varied across the floodplain, the horizontal variation in *n* option was used. The assignment of *n* was determined through use of 1-meter color infrared imagery and photograph-documented field visits.

Normal depth was assumed as the downstream boundary condition in this model, with a slope of 0.0017, measured from 20 foot contours on the USGS 7.5-minute quadrangle map.

Two USGS streamgages have or currently exist near the upstream limit of this reach. A historic gage, Powder River near Kaycee (06312500), with a watershed area of 980 mi^2, was operated by the U.S. Geological Survey (USGS) from 1934 to 1980 (39 years). Annual peak flows for this gage ranged from 402 cfs to 5230 cfs (on 5/10/1956 and 8/11/1941, respectively) and has an associated log-Pearson based 100-year flow of 6190 cfs. A currently operated gage, *Powder River at Sussex* (06313500), with a watershed area of 3090 mi^2, has been operated by the USGS from 1938 to ’40, 1951-’57, and 1978 to current (32 years). This gage measured annual peak flows ranging from 975 cfs to 32,500 cfs (on 5/30/1990 and 5/23/1952, respectively) and has an associated log-Pearson based 100-year flow of 46,600 cfs.

LIKELY INUNDATION EXTENT AND TIMING

This analysis provides a prediction of the extent and timing of flooding from a catastrophic breach of the Dullknife dam embankment. These results are sufficient for determining the hazard classification, estimating the economic impacts from a breach, and for developing an emergency action plan for such a situation. However, due to limitations in the understanding of and ability to model flow dynamics of such a severe, abrupt, and debris saturated breach wave within a steep, wooded channel (the canyon reach in particular), the modeling only provides an approximation of what will actually occur. **For these reasons, the results of this analysis should be considered approximate. The nature and limitations of these predictions must be kept in mind when using these results.**

A catastrophic breach of Dullknife dam, with an initial peak flow of about 160,000 cfs, will inundate 58 miles of floodplains along the North Fork of the Powder River and the Powder River before attenuating to about 14,500 cfs in the Powder River at Sussex. This is approximately a 12-year event for this point on the Powder River (see discharge-frequency computations in Appendix C). Figure 42 provides the routed breach hydrographs at seven points within the analysis zone. In the case of such a breach, dozens of homes and ranches will be threatened with damage or destruction, several highways and one interstate will be inundated (overtopped), bridges may be damaged, and lives could be lost.

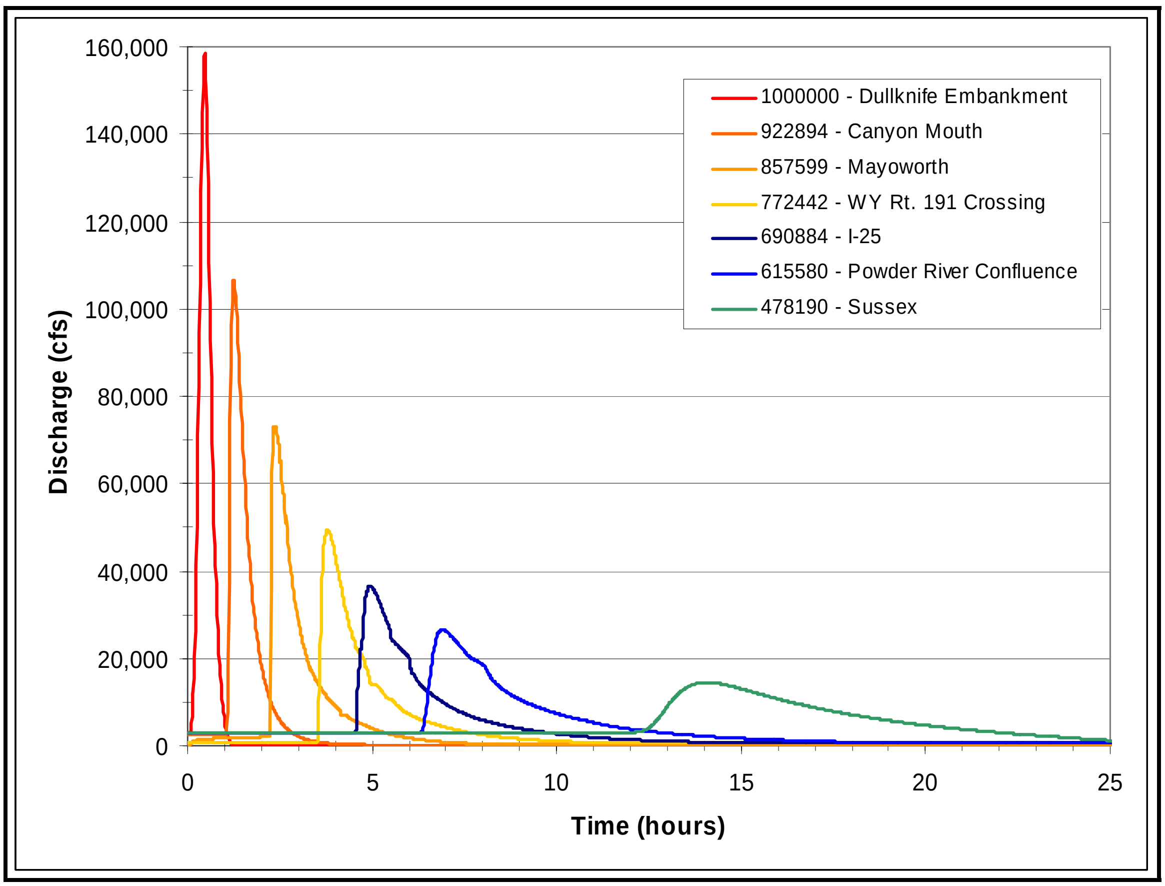


Figure 42: Breach hydrographs.

The probable inundation extent and timing is provided on the inundation maps of Appendix A. These twelve maps, which were created using ArcMAP 8.3, provide a probable inundation extent superimposed upon 1-meter resolution color-infrared imagery. Tables imbedded within these plots (and elaborated upon in Appendix B) indicate peak discharge at each section, approximate maximum depth and velocities, and breach wave timing and steepness for selected sections. Also included within these plots are photographs of selected structures that will be threatened by a breach, with the associated times to initial and peak inundation provided for convenience. A key to these maps is provided in Figure 43.

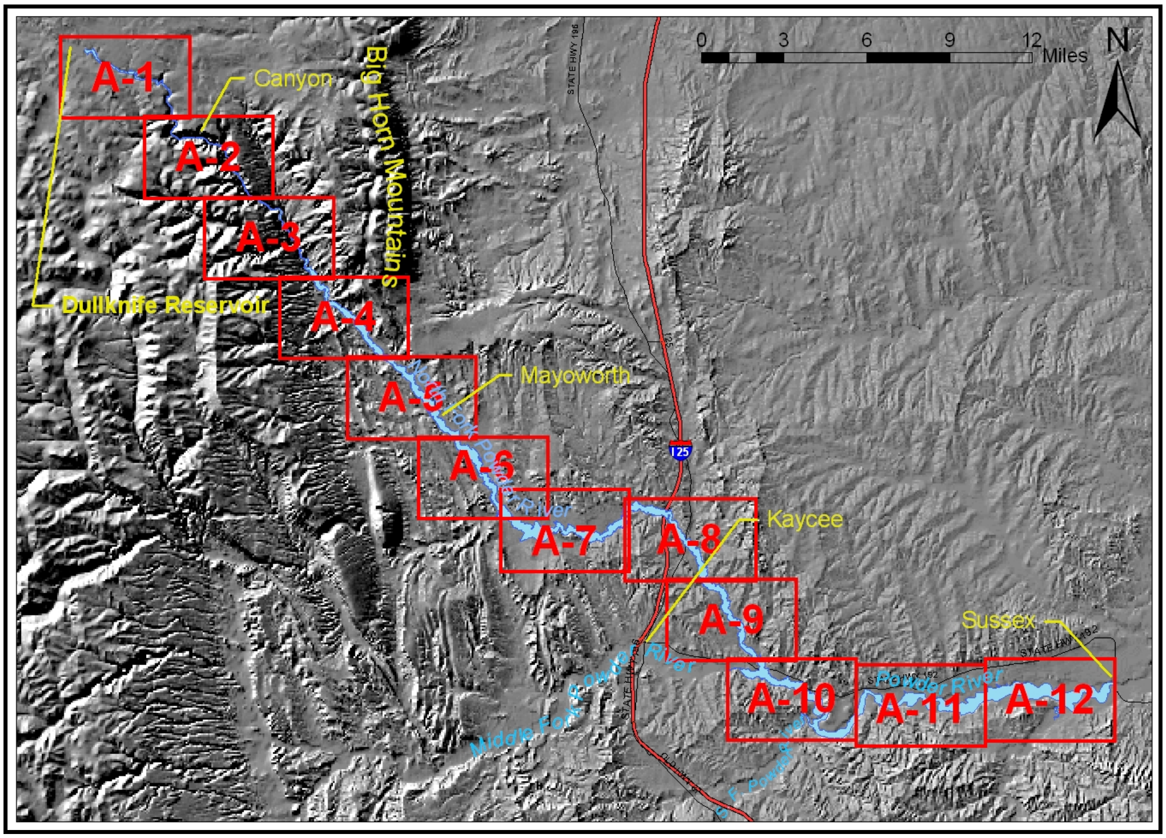


Figure 43: Probable inundation map key.

Based upon the unsteady flow analysis through the North Fork of the Powder River and the Powder River, the following scenario is presented as the likely worst-case result of a catastrophic breach of the Dullknife dam embankment.

A breach of the embankment dam may occur from either overtopping, piping failure, or embankment sliding or settlement. With an initially completely filled reservoir (a worst-case breach), a hydrograph with a peak of approximately **160,000 cfs** and a volume of 5100 ac-ft will result. The time-to-peak of this hydrograph is estimated to be 37 minutes. The resulting floodwave will envelope the entire valley bottom of the North Fork of the Powder River for the entire 13.9 mile (valley length) canyon reach, to the mouth of the canyon on the Hat Ranch. At this point peak flow will likely be attenuated to **107,000 cfs**, which is more than 67-times greater than the maximum recorded flow of 1590 cfs (in 1984) and almost 38-times greater than the estimated 100-year flow of 2,820 cfs

(Appendix C). Peak flow depths will range from 23 to 62 feet within this reach, with average peak channel velocities ranging from 15 to 56 ft/s and floodplain velocities ranging from 3 to 30 ft/s. The time-to-peak of the floodwave will shorten from 37 minutes at the dam to 15 minutes at the mouth of the canyon. Due to the steep, wooded, alluvium-bedded nature of this reach, this extreme flow will likely cause a great deal of woody debris liberation and bed scouring, with channel erosion in the tens of feet and the stripping of most vegetation within the flood path. It may be the case that as more of the floodway is inundated and stripped, the resulting debris flow will periodically lose its capacity to transport this entrained debris, become subcritical, and set up a temporary debris dam which will shortly break, remobilizing a portion of the debris dam until another dam is formed downstream. The floodwave leading edge and peak will take approximately **1.0 and 1.3 hours**, respectively, to reach the canyon mouth.

As the floodwave proceeds down the North Fork of the Powder River, flow will attenuate from **107,000 cfs** to **58,700 cfs** at Mayoworth downstream of the bridge for this 8.1 mile stretch. The floodwave's leading edge and peak will take **2.3 and 2.6 hours**, respectively, to reach section 848,645, two sections downstream of the Mayoworth bridge. Peak flow depths in this reach will range from 9 to 23 feet, with average peak channel velocities of 9 to 29 ft/s and floodplain velocities ranging from 3 to 14 ft/s. Time-to-peak will range from 8 to 18 minutes within this stretch. The Mayoworth Bridge will be overtopped and bridge failure due to abutment or pier scour is a possibility. Homes, roads, structures, and lives will be threatened.

As the floodwave proceeds from Mayoworth to just below the Rt. 191 bridge over the North Fork of the Powder River, flow will attenuate from **58,700 cfs** to **49,000 cfs** in this 6.4 mile stretch. The floodwave's leading edge and peak will take **3.5 and 3.8 hours**, respectively, to reach section 768422, a few sections below the Rt. 191 bridge. Peak flow depths in this reach will range from 10 to 24 feet, with average peak channel velocities of 8 to 23 ft/s and floodplain velocities ranging from 3 to 11 ft/s. Time-to-peak will range from 11 to 28 minutes within this reach. The Rt. 191 bridge will be overtopped, bridge failure due to abutment or pier scour is a possibility, and homes, roads, structures, and lives will be threatened.

Downstream of the Rt. 191 bridge to the confluence of the North Fork of the Powder River with the Middle Fork of the Powder River, the floodwave will attenuate in this 14.2-mile reach from **49,000 cfs** to **24,800 cfs** at section 613010, just below the confluence. The floodwave's leading edge and peak will take **6.4 and 7.1 hours**, respectively, to reach section 613010, a few sections downstream of the Rt. 192 bridge. At this point the peak flow of **24,800 cfs** will be almost 5-times the maximum recorded flow of 5230 cfs (in 1941) and 4-times greater than the estimated 100-year flow of 6190 cfs (Appendix C). Peak flow depths in this reach will range from 12 to 22 feet, with average peak channel velocities of 4 to 21 ft/s and floodplain velocities ranging from 1 to 11 ft/s. Time-to-peak will range from 12 to 40 minutes within this reach. Flow over the I-25, Rt. 196, and Rt. 192 bridge embankments are likely. Bridge failure due to abutment or pier scour is a possibility. Danger exists to any vehicles (and occupants) caught in the possible overflow or failure. Within this reach numerous homes, roads, structures, and lives will also be threatened.

Within the 16.3-mile valley length stretch of the Powder River that was modeled in this analysis, the floodwave's peak flow will attenuate from **24,800 cfs** to **14,500 cfs**, with the floodwave leading edge and peak flow arriving at section 478190 (at Sussex) at **12.0 and 14.1 hours,** respectively. Time-to-peak will be 122 minutes at this section. Peak flow depths in this reach will range from 10 to 17 feet, with average peak channel velocities of 4 to 13 ft/s and floodplain velocities ranging from 1 to 8 ft/s. Time-to-peak will range from 40 to 122 minutes within this reach. At Sussex the 14,500 cfs flow is approximately a 12-year event. This flow, which will continue to attenuate, will have minimal potential for danger to structures and lives within the sparsely-populated Powder River valley downstream of Sussex.

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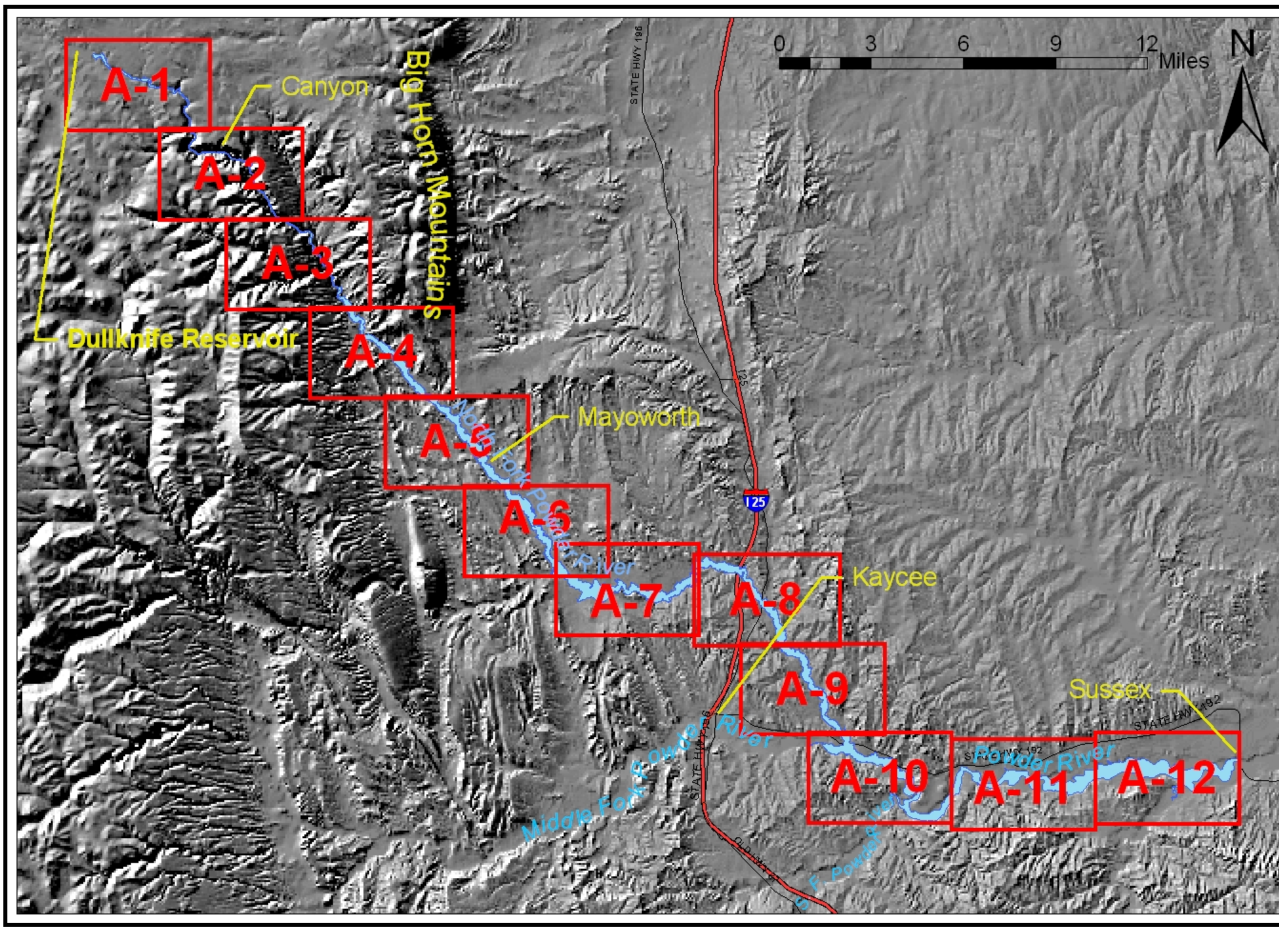
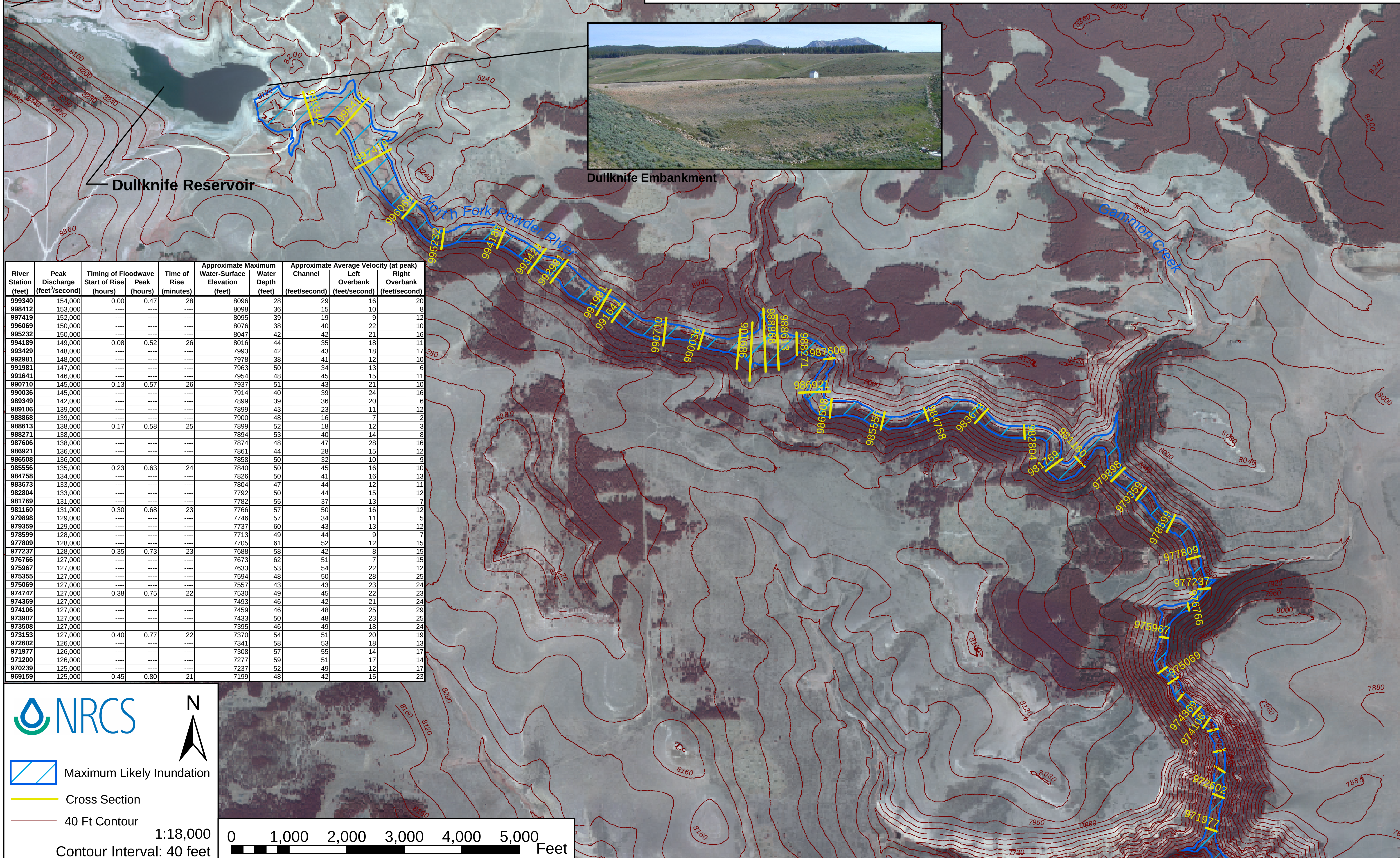
Appendix A
Maximum Likely Inundation Mapping



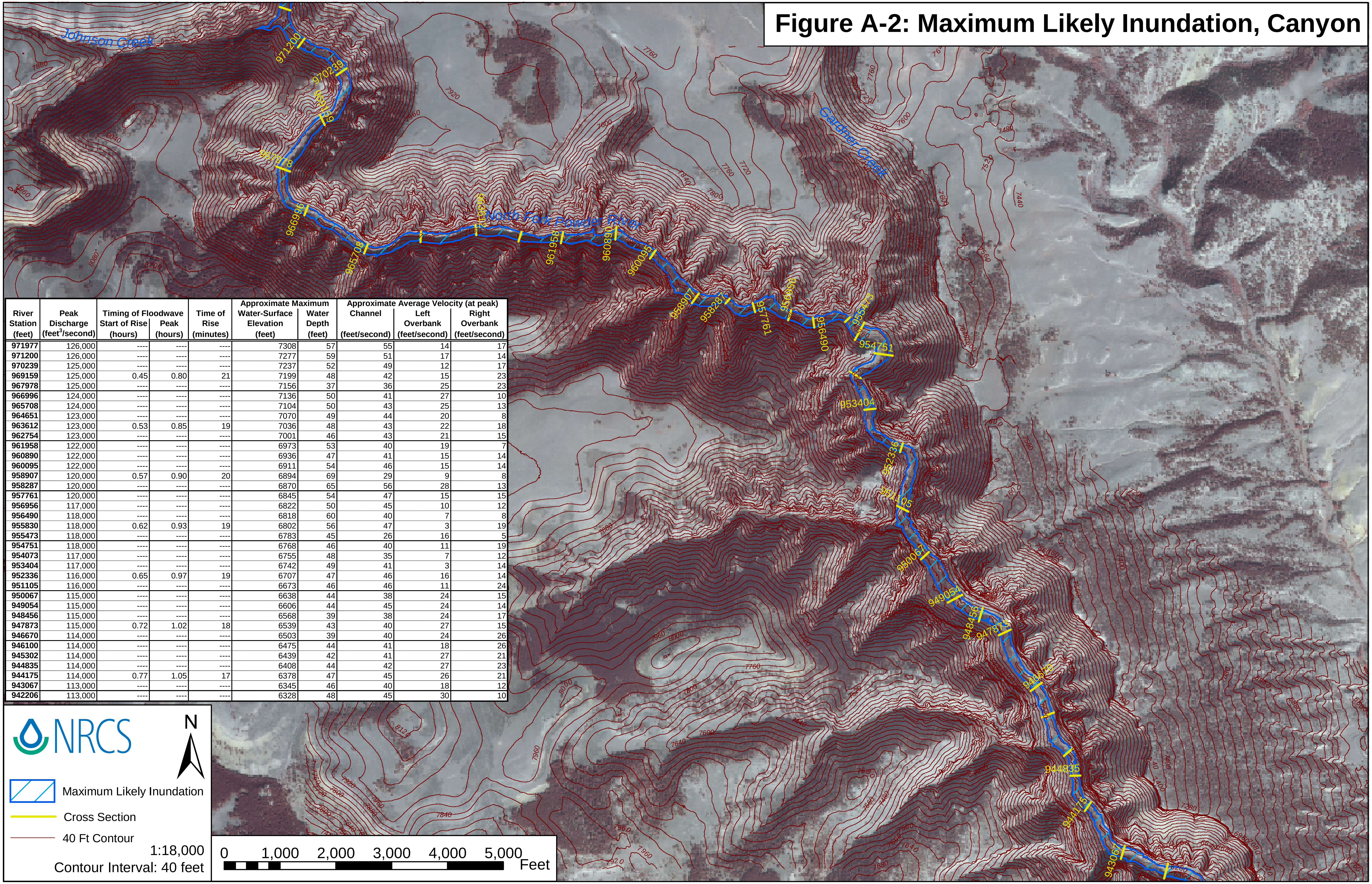
A-1: Maximum Likely Inundation, Dullknife Reservoir
A-2: Maximum Likely Inundation, Canyon
A-3: Maximum Likely Inundation, Canyon Mouth
A-4: Maximum Likely Inundation, Hat Ranch
A-5: Maximum Likely Inundation, Mayoworth
A-6: Maximum Likely Inundation, Rt. 191
A-7: Maximum Likely Inundation, Rt. 191 Crossing
A-8: Maximum Likely Inundation, I-25
A-9: Maximum Likely Inundation, Lower North Fork
A-10: Maximum Likely Inundation, Powder River Confluence
A-11: Maximum Likely Inundation, Powder River
A-12: Maximum Likely Inundation, Sussex

Figure A-1: Maximum Likely Inundation, Dullknife Reservoir



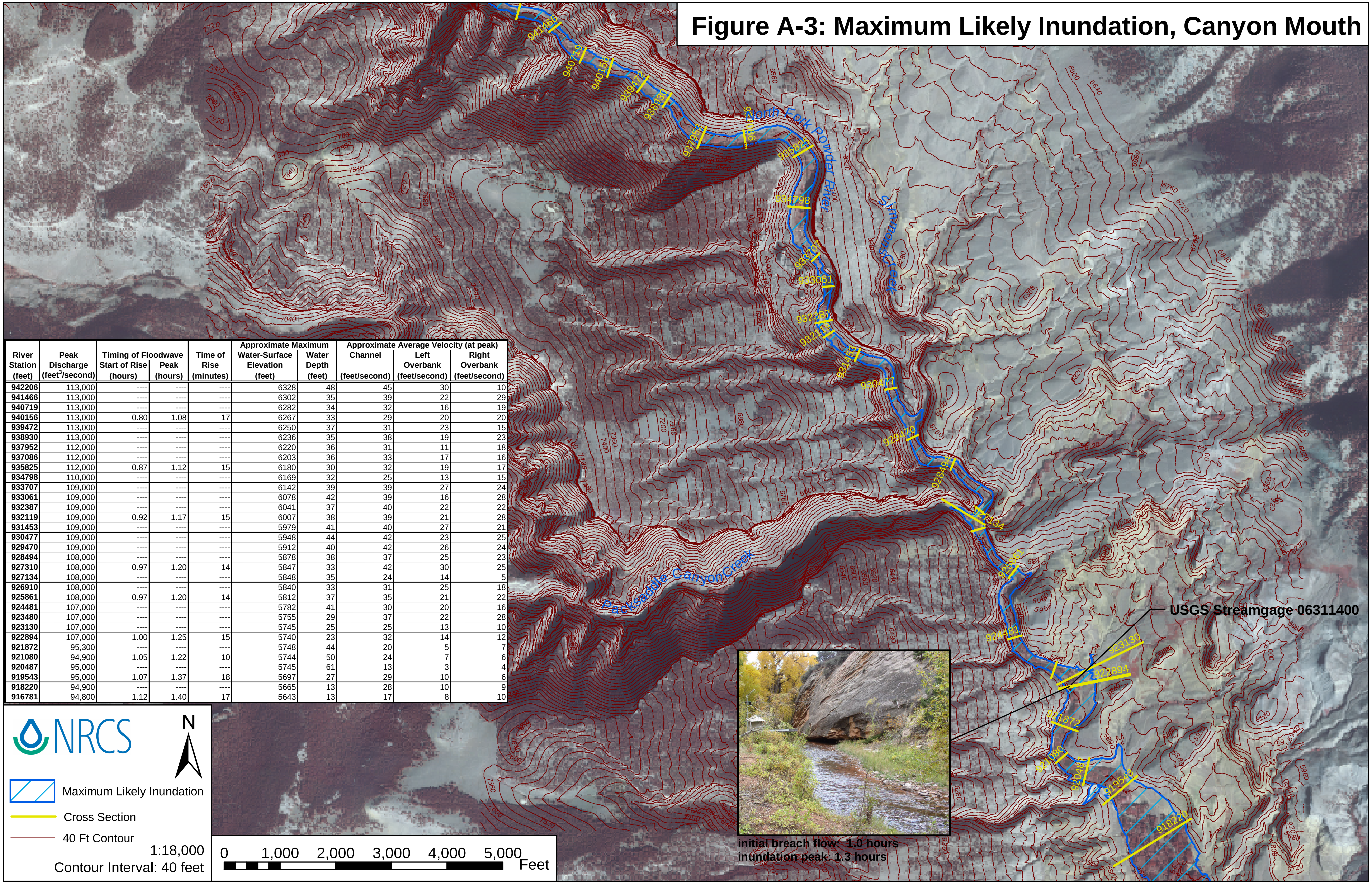
River Station (feet)	Peak Discharge ($feet^3$/second)	Timing of Floodwave: Start of Rise (hours)	Timing of Floodwave: Peak (hours)	Time of Rise (minutes)	Approximate Maximum: Water-Surface Elevation (feet)	Approximate Maximum: Water Depth (feet)	Approximate Average Velocity (at peak): Channel (feet/second)	Approximate Average Velocity (at peak): Left Overbank (feet/second)	Approximate Average Velocity (at peak): Right Overbank (feet/second)
999340	154,000	0.00	0.47	28	8096	28	29	16	20
998412	153,000	----	----	----	8098	36	15	10	8
997419	152,000	----	----	----	8095	39	19	9	12
996069	150,000	----	----	----	8076	38	40	22	10
995232	150,000	----	----	----	8047	42	42	21	16
994189	149,000	0.08	0.52	26	8016	44	35	18	11
993429	148,000	----	----	----	7993	42	43	18	17
992981	148,000	----	----	----	7978	38	41	12	10
991981	147,000	----	----	----	7963	50	34	13	6
991641	146,000	----	----	----	7954	48	45	15	11
990710	145,000	0.13	0.57	26	7937	51	43	21	10
990036	145,000	----	----	----	7914	40	39	24	16
989349	142,000	----	----	----	7899	39	36	20	6
989106	139,000	----	----	----	7899	43	23	11	12
988868	139,000	----	----	----	7900	48	16	7	2
988613	138,000	0.17	0.58	25	7899	52	18	12	3
988271	138,000	----	----	----	7894	53	40	14	8
987606	138,000	----	----	----	7874	48	47	28	16
986921	136,000	----	----	----	7861	44	28	15	12
986508	136,000	----	----	----	7858	50	32	10	9
985556	135,000	0.23	0.63	24	7840	50	45	16	10
984758	134,000	----	----	----	7826	50	41	16	13
983673	133,000	----	----	----	7804	47	44	12	11
982804	133,000	----	----	----	7792	50	44	15	12
981769	131,000	----	----	----	7782	55	37	13	7
981160	131,000	0.30	0.68	23	7766	57	50	16	12
979898	129,000	----	----	----	7746	57	34	11	5
979359	129,000	----	----	----	7737	60	43	13	12
978599	128,000	----	----	----	7713	49	44	9	7
977809	128,000	----	----	----	7705	61	52	12	15
977237	128,000	0.35	0.73	23	7688	58	42	8	15
976766	127,000	----	----	----	7673	62	51	7	15
975967	127,000	----	----	----	7633	53	54	22	12
975355	127,000	----	----	----	7594	48	50	28	25
975069	127,000	----	----	----	7557	43	43	23	24
974747	127,000	0.38	0.75	22	7530	49	45	22	23
974369	127,000	----	----	----	7493	46	42	21	24
974106	127,000	----	----	----	7459	46	48	25	29
973907	127,000	----	----	----	7433	50	48	23	25
973508	127,000	----	----	----	7395	46	49	18	24
973153	127,000	0.40	0.77	22	7370	54	51	20	19
972602	126,000	----	----	----	7341	58	53	18	13
971977	126,000	----	----	----	7308	57	55	14	17
971200	126,000	----	----	----	7277	59	51	17	14
970239	125,000	----	----	----	7237	52	49	12	17
969159	125,000	0.45	0.80	21	7199	48	42	15	23

Figure A-2: Maximum Likely Inundation, Canyon



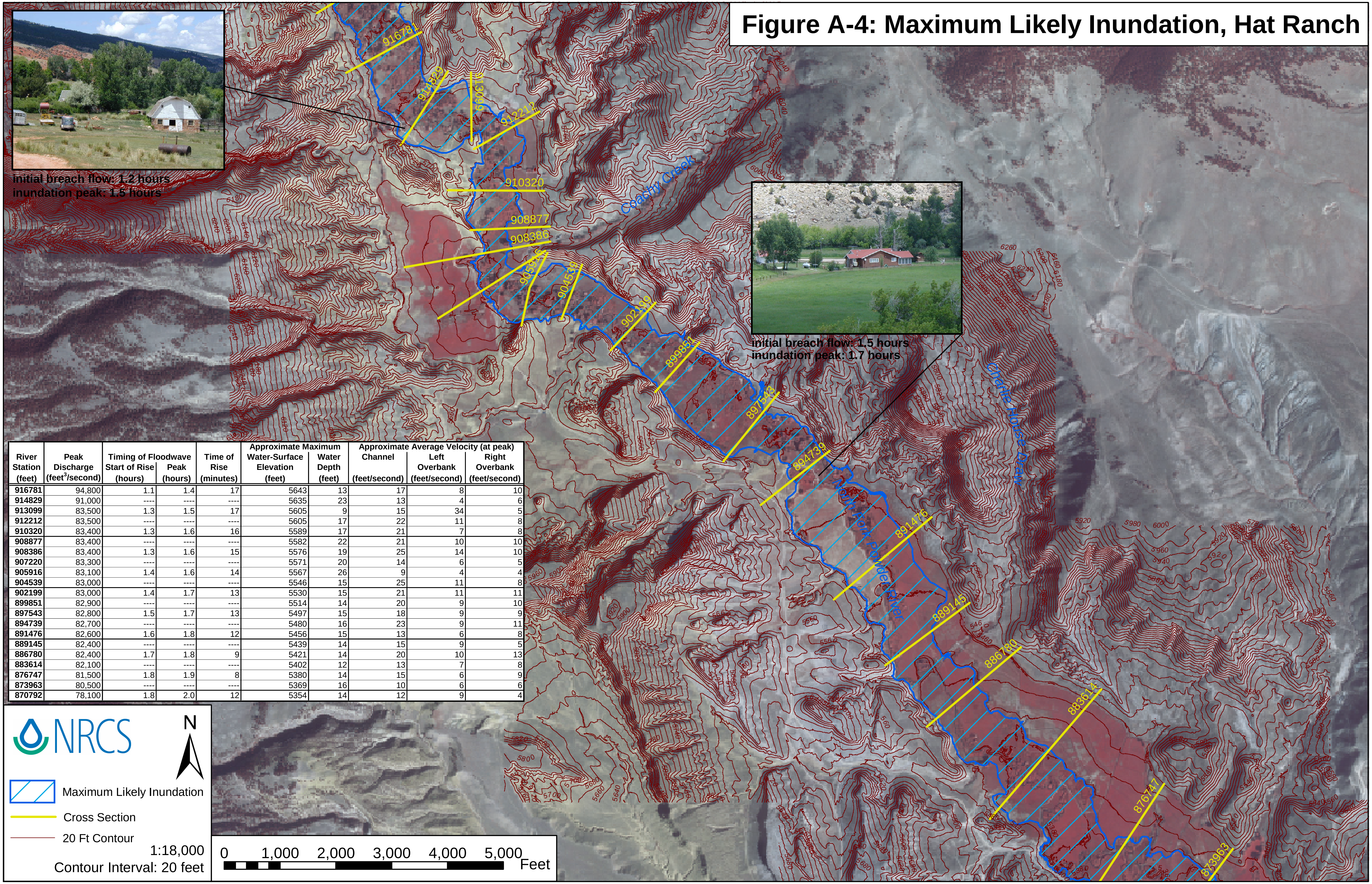
River Station (feet)	Peak Discharge (feet³/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
971977	126,000	----	----	----	7308	57	55	14	17
971200	126,000	----	----	----	7277	59	51	17	14
970239	125,000	----	----	----	7237	52	49	12	17
969159	125,000	0.45	0.80	21	7199	48	42	15	23
967978	125,000	----	----	----	7156	37	36	25	23
966996	124,000	----	----	----	7136	50	41	27	10
965708	124,000	----	----	----	7104	50	43	25	13
964651	123,000	----	----	----	7070	49	44	20	8
963612	123,000	0.53	0.85	19	7036	48	43	22	18
962754	123,000	----	----	----	7001	46	43	21	15
961958	122,000	----	----	----	6973	53	40	19	7
960890	122,000	----	----	----	6936	47	41	15	14
960095	122,000	----	----	----	6911	54	46	15	14
958907	120,000	0.57	0.90	20	6894	69	29	9	8
958287	120,000	----	----	----	6870	65	56	28	13
957761	120,000	----	----	----	6845	54	47	15	15
956956	117,000	----	----	----	6822	50	45	10	12
956490	118,000	----	----	----	6818	60	40	7	8
955830	118,000	0.62	0.93	19	6802	56	47	3	19
955473	118,000	----	----	----	6783	45	26	16	5
954751	118,000	----	----	----	6768	46	40	11	19
954073	117,000	----	----	----	6755	48	35	7	12
953404	117,000	----	----	----	6742	49	41	3	14
952336	116,000	0.65	0.97	19	6707	47	46	16	14
951105	116,000	----	----	----	6673	46	46	11	24
950067	115,000	----	----	----	6638	44	38	24	15
949054	115,000	----	----	----	6606	44	45	24	14
948456	115,000	----	----	----	6568	39	38	24	17
947873	115,000	0.72	1.02	18	6539	43	40	27	15
946670	114,000	----	----	----	6503	39	40	24	26
946100	114,000	----	----	----	6475	44	41	18	26
945302	114,000	----	----	----	6439	42	41	27	21
944835	114,000	----	----	----	6408	44	42	27	23
944175	114,000	0.77	1.05	17	6378	47	45	26	21
943067	113,000	----	----	----	6345	46	40	18	12
942206	113,000	----	----	----	6328	48	45	30	10

Figure A-3: Maximum Likely Inundation, Canyon Mouth



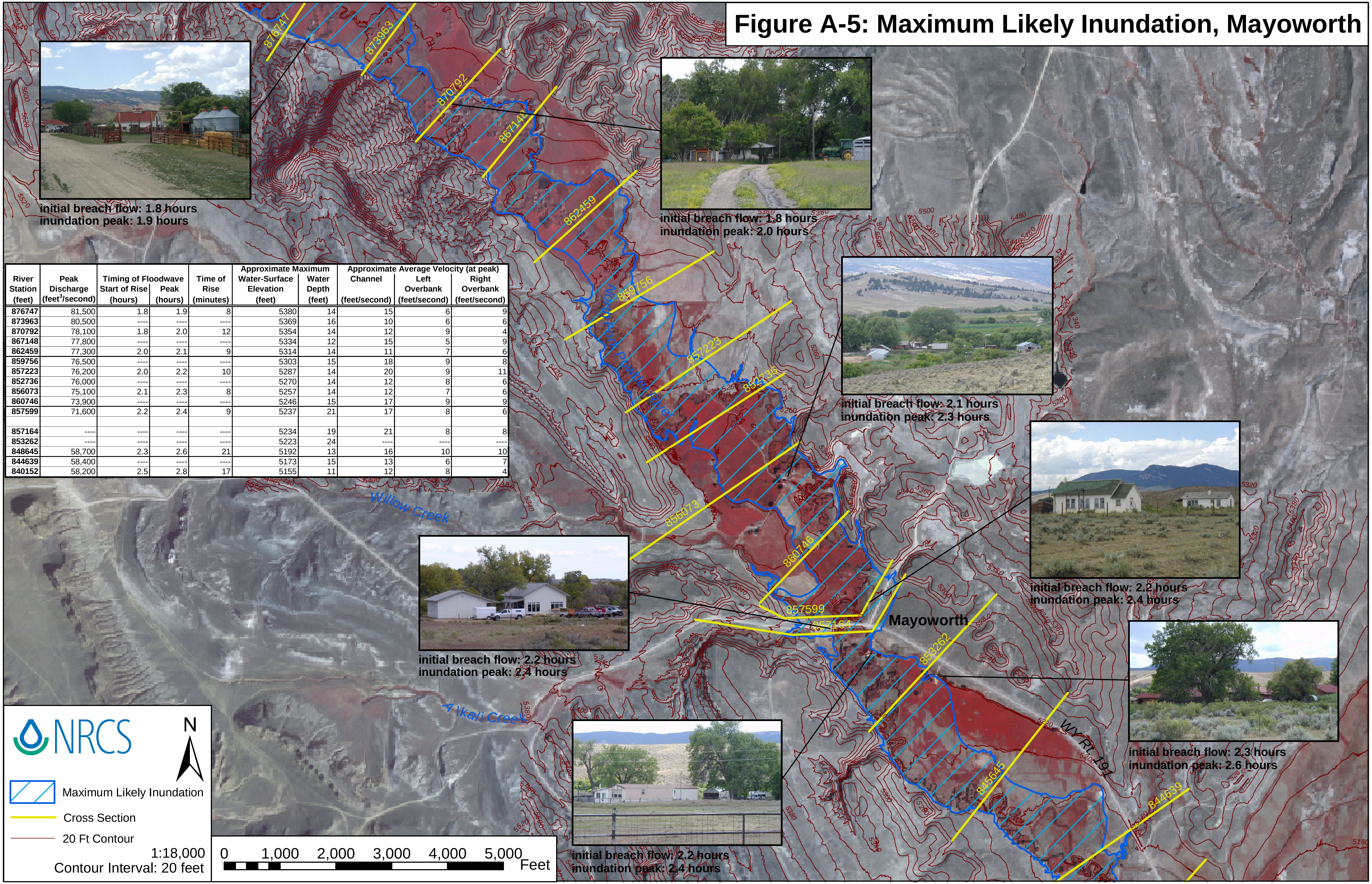
River Station (feet)	Peak Discharge (feet³/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
942206	113,000	----	----	----	6328	48	45	30	10
941466	113,000	----	----	----	6302	35	39	22	29
940719	113,000	----	----	----	6282	34	32	16	19
940156	113,000	0.80	1.08	17	6267	33	29	20	20
939472	113,000	----	----	----	6250	37	31	23	15
938930	113,000	----	----	----	6236	35	38	19	23
937952	112,000	----	----	----	6220	36	31	11	18
937086	112,000	----	----	----	6203	36	33	17	16
935825	112,000	0.87	1.12	15	6180	30	32	19	17
934798	110,000	----	----	----	6169	32	25	13	15
933707	109,000	----	----	----	6142	39	39	27	24
933061	109,000	----	----	----	6078	42	39	16	28
932387	109,000	----	----	----	6041	37	40	22	22
932119	109,000	0.92	1.17	15	6007	38	39	21	28
931453	109,000	----	----	----	5979	41	40	27	21
930477	109,000	----	----	----	5948	44	42	23	25
929470	109,000	----	----	----	5912	40	42	26	24
928494	108,000	----	----	----	5878	38	37	25	23
927310	108,000	0.97	1.20	14	5847	33	42	30	25
927134	108,000	----	----	----	5848	35	24	14	5
926910	108,000	----	----	----	5840	33	31	25	18
925861	108,000	0.97	1.20	14	5812	37	35	21	22
924481	107,000	----	----	----	5782	41	30	20	16
923480	107,000	----	----	----	5755	29	37	22	28
923130	107,000	----	----	----	5745	25	25	13	10
922894	107,000	1.00	1.25	15	5740	23	32	14	12
921872	95,300	----	----	----	5748	44	20	5	7
921080	94,900	1.05	1.22	10	5744	50	24	7	6
920487	95,000	----	----	----	5745	61	13	3	4
919543	95,000	1.07	1.37	18	5697	27	29	10	6
918220	94,900	----	----	----	5665	13	28	10	9
916781	94,800	1.12	1.40	17	5643	13	17	8	10

Figure A-4: Maximum Likely Inundation, Hat Ranch



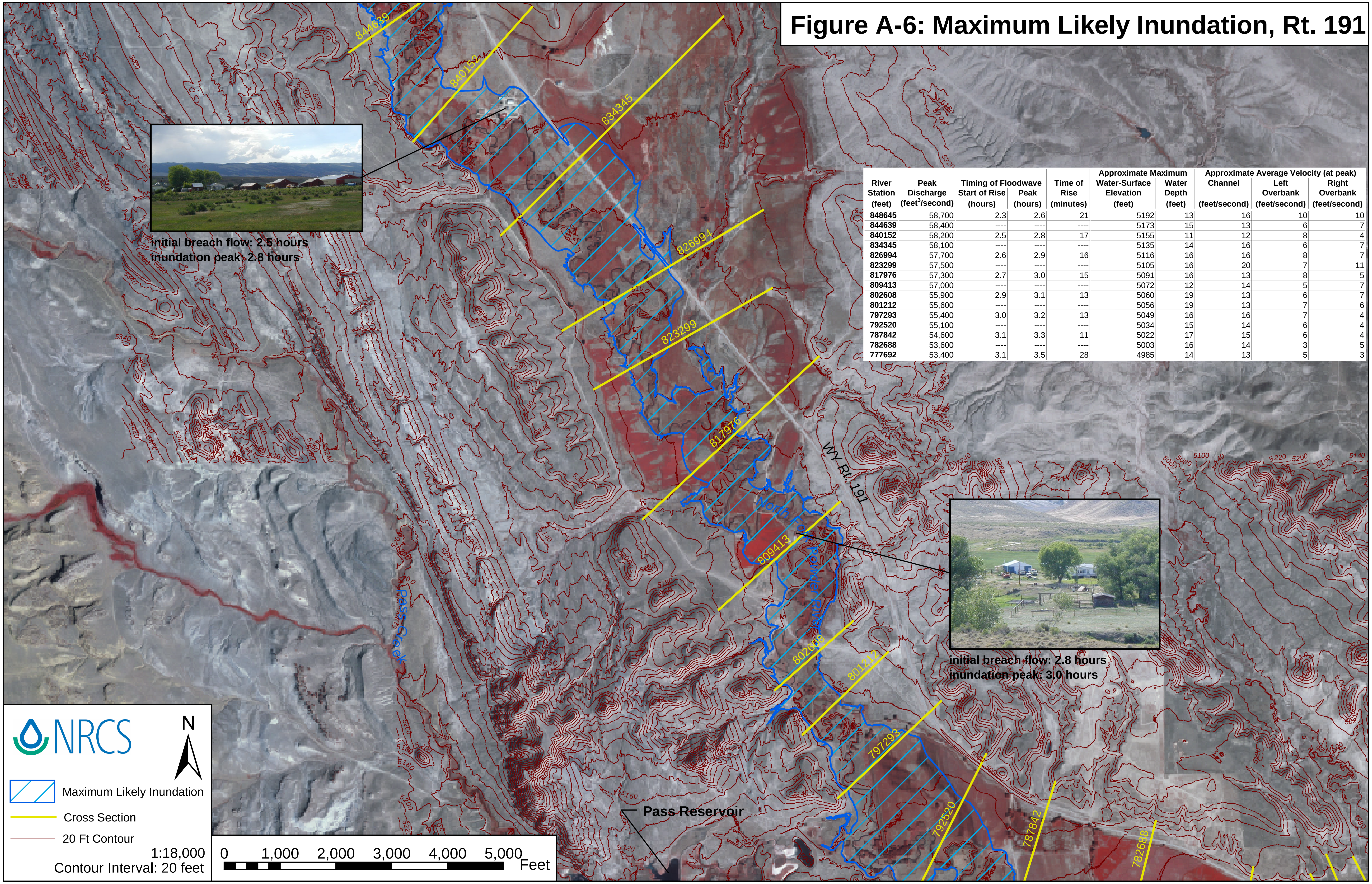
River Station (feet)	Peak Discharge ($feet^3$/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
916781	94,800	1.1	1.4	17	5643	13	17	8	10
914829	91,000	----	----	----	5635	23	13	4	6
913099	83,500	1.3	1.5	17	5605	9	15	34	5
912212	83,500	----	----	----	5605	17	22	11	8
910320	83,400	1.3	1.6	16	5589	17	21	7	8
908877	83,400	----	----	----	5582	22	21	10	10
908386	83,400	1.3	1.6	15	5576	19	25	14	10
907220	83,300	----	----	----	5571	20	14	6	5
905916	83,100	1.4	1.6	14	5567	26	9	4	4
904539	83,000	----	----	----	5546	15	25	11	8
902199	83,000	1.4	1.7	13	5530	15	21	11	11
899851	82,900	----	----	----	5514	14	20	9	10
897543	82,800	1.5	1.7	13	5497	15	18	9	9
894739	82,700	----	----	----	5480	16	23	9	11
891476	82,600	1.6	1.8	12	5456	15	13	6	8
889145	82,400	----	----	----	5439	14	15	9	5
886780	82,400	1.7	1.8	9	5421	14	20	10	13
883614	82,100	----	----	----	5402	12	13	7	8
876747	81,500	1.8	1.9	8	5380	14	15	6	9
873963	80,500	----	----	----	5369	16	10	6	6
870792	78,100	1.8	2.0	12	5354	14	12	9	4

Figure A-5: Maximum Likely Inundation, Mayoworth



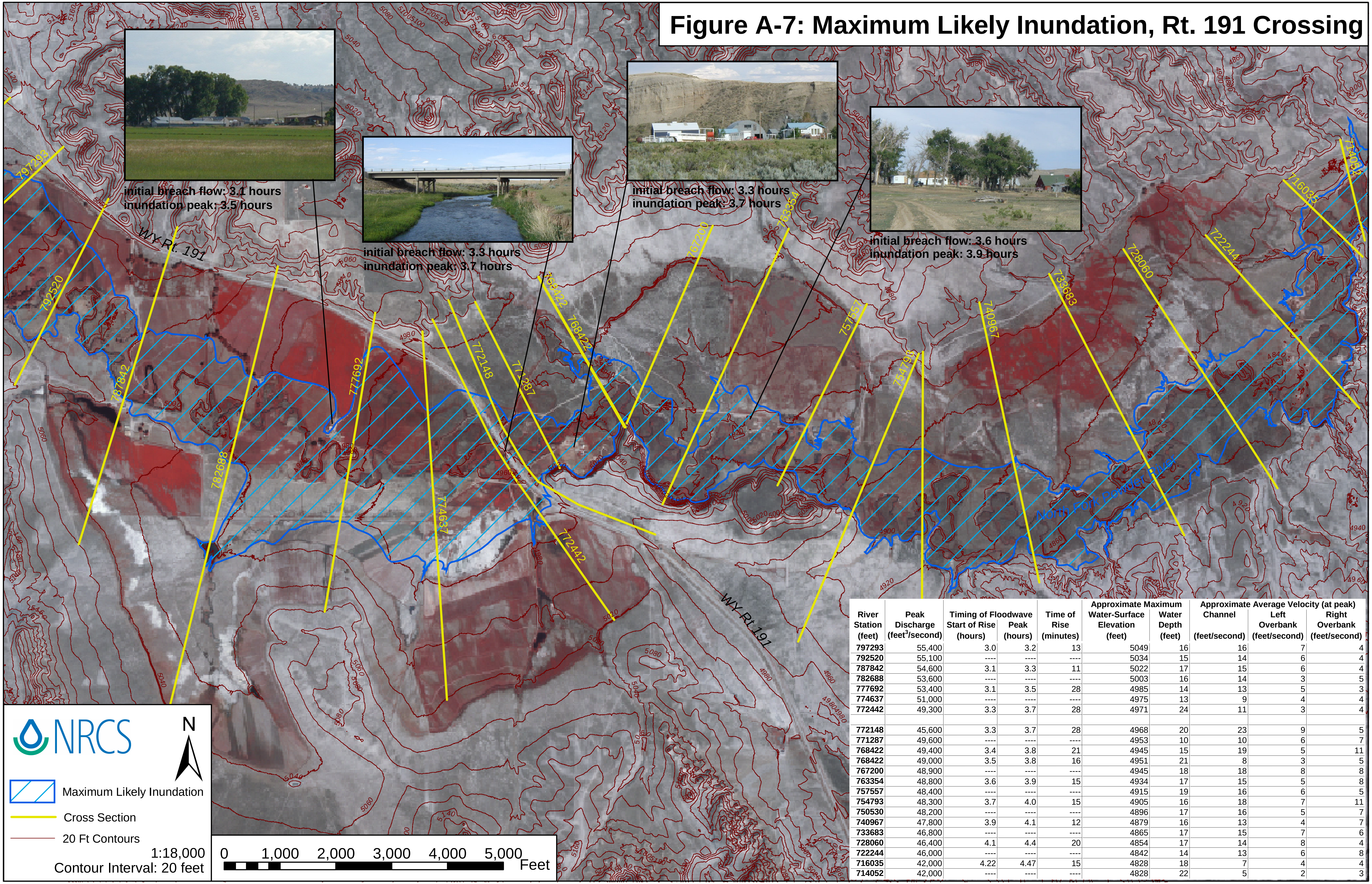
River Station (feet)	Peak Discharge (feet³/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
876747	81,500	1.8	1.9	8	5380	14	15	6	9
873963	80,500	----	----	----	5369	16	10	6	6
870792	78,100	1.8	2.0	12	5354	14	12	9	4
867148	77,800	----	----	----	5334	12	15	5	9
862459	77,300	2.0	2.1	9	5314	14	11	7	6
859756	76,500	----	----	----	5303	15	18	9	8
857223	76,200	2.0	2.2	10	5287	14	20	9	11
852736	76,000	----	----	----	5270	14	12	8	6
856073	75,100	2.1	2.3	8	5257	14	12	7	6
860746	73,900	----	----	----	5246	15	17	9	9
857599	71,600	2.2	2.4	9	5237	21	17	8	6
857164	----	----	----	----	5234	19	21	8	8
853262	----	----	----	----	5223	24	----	----	----
848645	58,700	2.3	2.6	21	5192	13	16	10	10
844639	58,400	----	----	----	5173	15	13	6	7
840152	58,200	2.5	2.8	17	5155	11	12	8	4

Figure A-6: Maximum Likely Inundation, Rt. 191



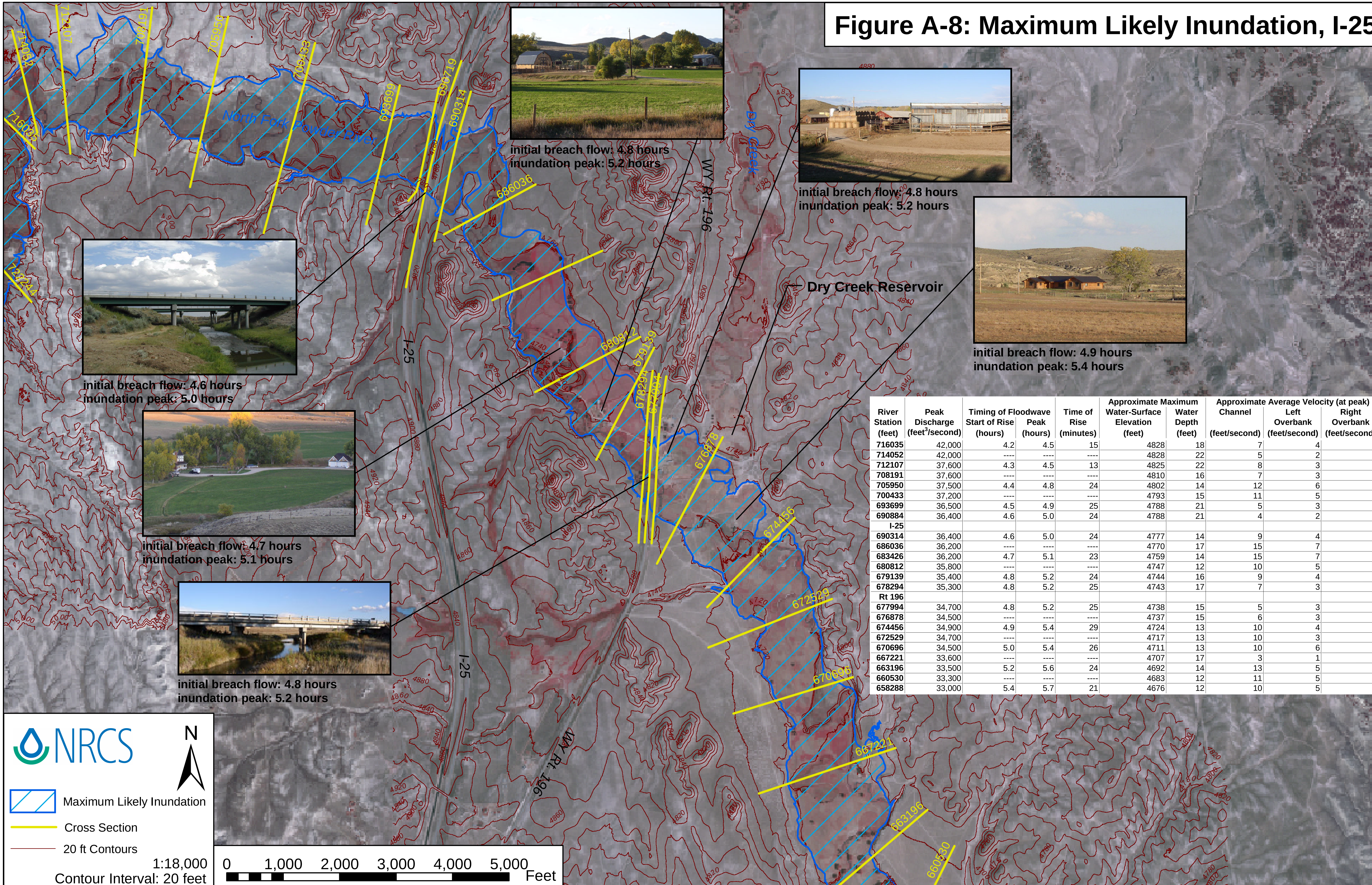
River Station (feet)	Peak Discharge (feet³/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
848645	58,700	2.3	2.6	21	5192	13	16	10	10
844639	58,400	----	----	----	5173	15	13	6	7
840152	58,200	2.5	2.8	17	5155	11	12	8	4
834345	58,100	----	----	----	5135	14	16	6	7
826994	57,700	2.6	2.9	16	5116	16	16	8	7
823299	57,500	----	----	----	5105	16	20	7	11
817976	57,300	2.7	3.0	15	5091	16	13	8	5
809413	57,000	----	----	----	5072	12	14	5	7
802608	55,900	2.9	3.1	13	5060	19	13	6	7
801212	55,600	----	----	----	5056	19	13	7	6
797293	55,400	3.0	3.2	13	5049	16	16	7	4
792520	55,100	----	----	----	5034	15	14	6	4
787842	54,600	3.1	3.3	11	5022	17	15	6	4
782688	53,600	----	----	----	5003	16	14	3	5
777692	53,400	3.1	3.5	28	4985	14	13	5	3

Figure A-7: Maximum Likely Inundation, Rt. 191 Crossing



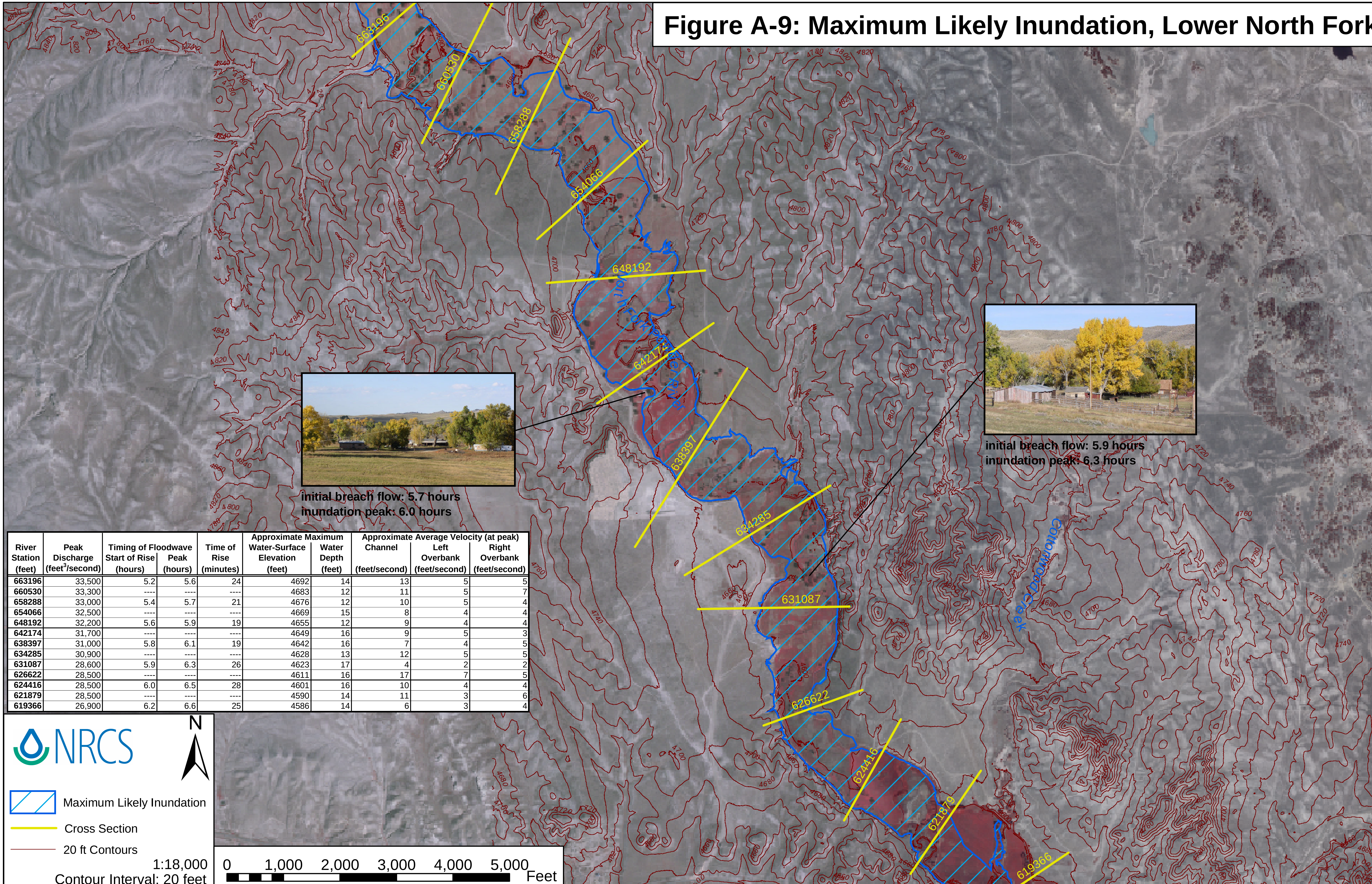
River Station (feet)	Peak Discharge (feet^3/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
797293	55,400	3.0	3.2	13	5049	16	16	7	4
792520	55,100	----	----	----	5034	15	14	6	4
787842	54,600	3.1	3.3	11	5022	17	15	6	4
782688	53,600	----	----	----	5003	16	14	3	5
777692	53,400	3.1	3.5	28	4985	14	13	5	3
774637	51,000	----	----	----	4975	13	9	4	4
772442	49,300	3.3	3.7	28	4971	24	11	3	4
772148	45,600	3.3	3.7	28	4968	20	23	9	5
771287	49,600	----	----	----	4953	10	10	6	7
768422	49,400	3.4	3.8	21	4945	15	19	5	11
768422	49,000	3.5	3.8	16	4951	21	8	3	5
767200	48,900	----	----	----	4945	18	18	8	8
763354	48,800	3.6	3.9	15	4934	17	15	5	8
757557	48,400	----	----	----	4915	19	16	6	5
754793	48,300	3.7	4.0	15	4905	16	18	7	11
750530	48,200	----	----	----	4896	17	16	5	7
740967	47,800	3.9	4.1	12	4879	16	13	4	7
733683	46,800	----	----	----	4865	17	15	7	6
728060	46,400	4.1	4.4	20	4854	17	14	8	4
722244	46,000	----	----	----	4842	14	13	6	8
716035	42,000	4.22	4.47	15	4828	18	7	4	4
714052	42,000	----	----	----	4828	22	5	2	3

Figure A-8: Maximum Likely Inundation, I-25



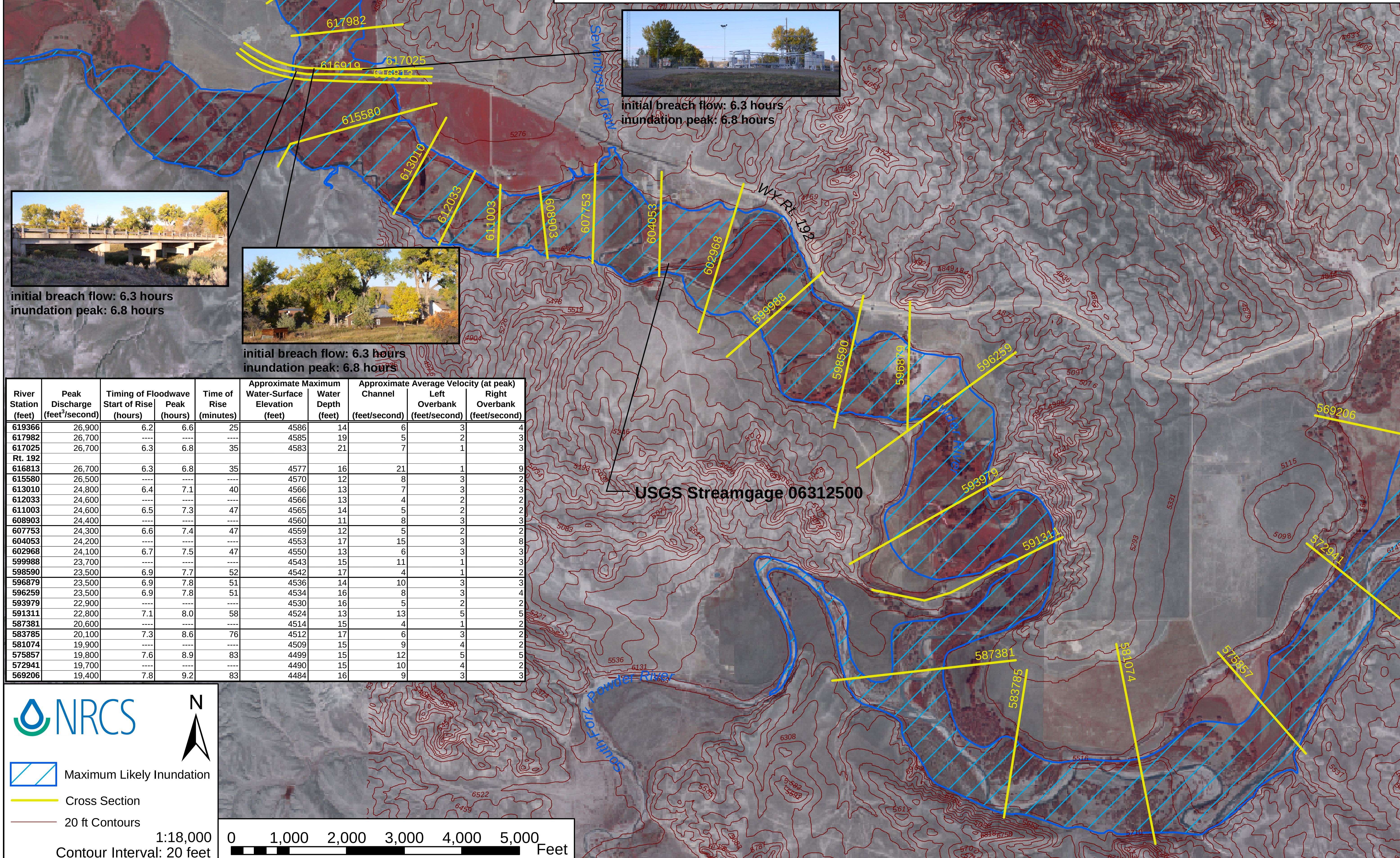
River Station (feet)	Peak Discharge (feet^3/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
716035	42,000	4.2	4.5	15	4828	18	7	4	4
714052	42,000	----	----	----	4828	22	5	2	3
712107	37,600	4.3	4.5	13	4825	22	8	3	4
708191	37,600	----	----	----	4810	16	7	3	4
705950	37,500	4.4	4.8	24	4802	14	12	6	6
700433	37,200	----	----	----	4793	15	11	5	4
693699	36,500	4.5	4.9	25	4788	21	5	3	2
690884	36,400	4.6	5.0	24	4788	21	4	2	2
I-25									
690314	36,400	4.6	5.0	24	4777	14	9	4	4
686036	36,200	----	----	----	4770	17	15	7	6
683426	36,200	4.7	5.1	23	4759	14	15	7	6
680812	35,800	----	----	----	4747	12	10	5	6
679139	35,400	4.8	5.2	24	4744	16	9	4	5
678294	35,300	4.8	5.2	25	4743	17	7	3	4
Rt 196									
677994	34,700	4.8	5.2	25	4738	15	5	3	3
676878	34,500	----	----	----	4737	15	6	3	2
674456	34,900	4.9	5.4	29	4724	13	10	4	5
672529	34,700	----	----	----	4717	13	10	3	6
670696	34,500	5.0	5.4	26	4711	13	10	6	5
667221	33,600	----	----	----	4707	17	3	1	2
663196	33,500	5.2	5.6	24	4692	14	13	5	5
660530	33,300	----	----	----	4683	12	11	5	7
658288	33,000	5.4	5.7	21	4676	12	10	5	4

Figure A-9: Maximum Likely Inundation, Lower North Fork



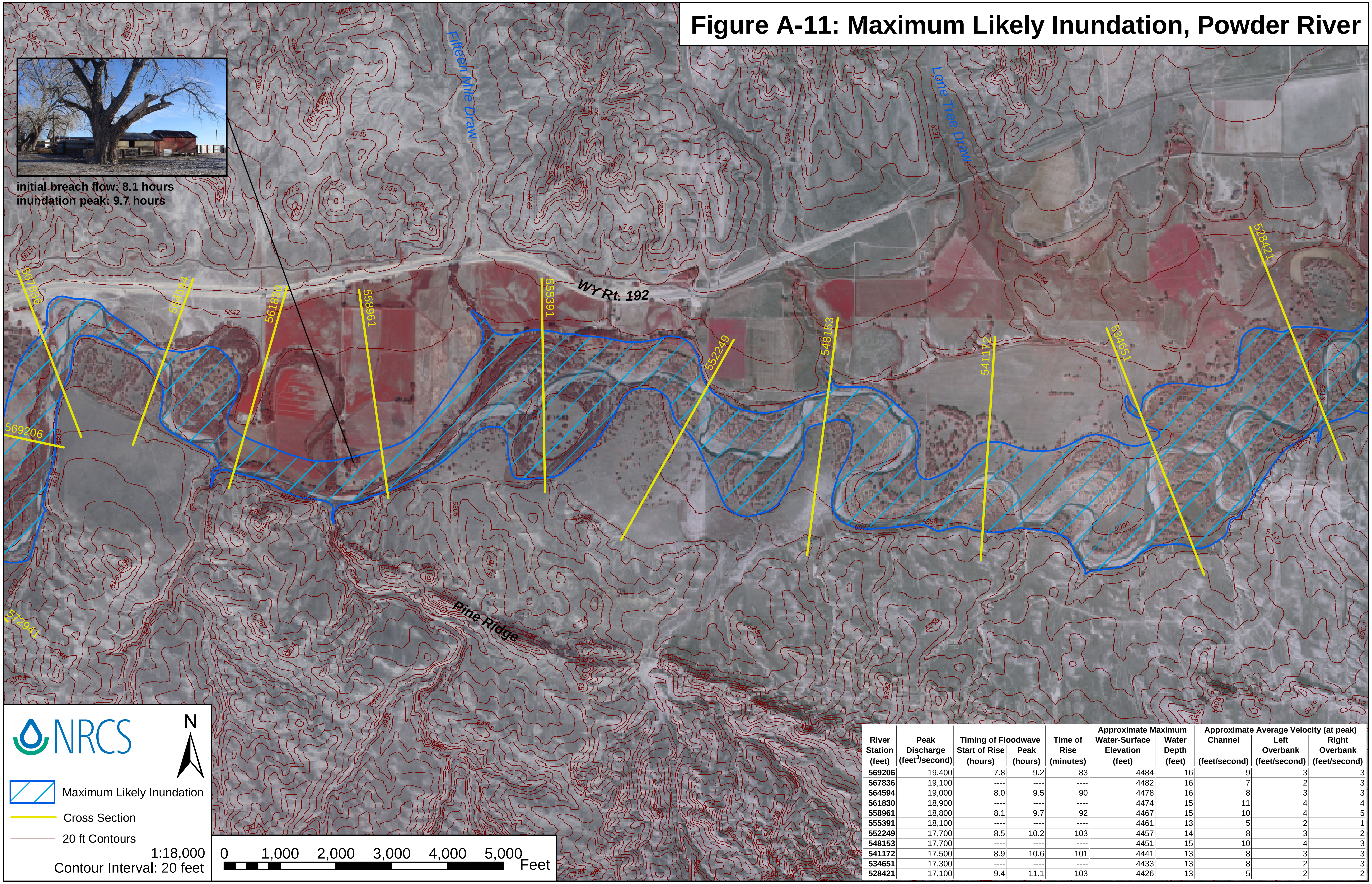
River Station (feet)	Peak Discharge (feet³/second)	Timing of Floodwave: Start of Rise (hours)	Timing of Floodwave: Peak (hours)	Time of Rise (minutes)	Approximate Maximum: Water-Surface Elevation (feet)	Approximate Maximum: Water Depth (feet)	Approximate Average Velocity (at peak): Channel (feet/second)	Approximate Average Velocity (at peak): Left Overbank (feet/second)	Approximate Average Velocity (at peak): Right Overbank (feet/second)
663196	33,500	5.2	5.6	24	4692	14	13	5	5
660530	33,300	----	----	----	4683	12	11	5	7
658288	33,000	5.4	5.7	21	4676	12	10	5	4
654066	32,500	----	----	----	4669	15	8	4	4
648192	32,200	5.6	5.9	19	4655	12	9	4	4
642174	31,700	----	----	----	4649	16	9	5	3
638397	31,000	5.8	6.1	19	4642	16	7	4	5
634285	30,900	----	----	----	4628	13	12	5	5
631087	28,600	5.9	6.3	26	4623	17	4	2	2
626622	28,500	----	----	----	4611	16	17	7	5
624416	28,500	6.0	6.5	28	4601	16	10	4	4
621879	28,500	----	----	----	4590	14	11	3	6
619366	26,900	6.2	6.6	25	4586	14	6	3	4

Figure A-10: Maximum Likely Inundation, Powder River Confluence



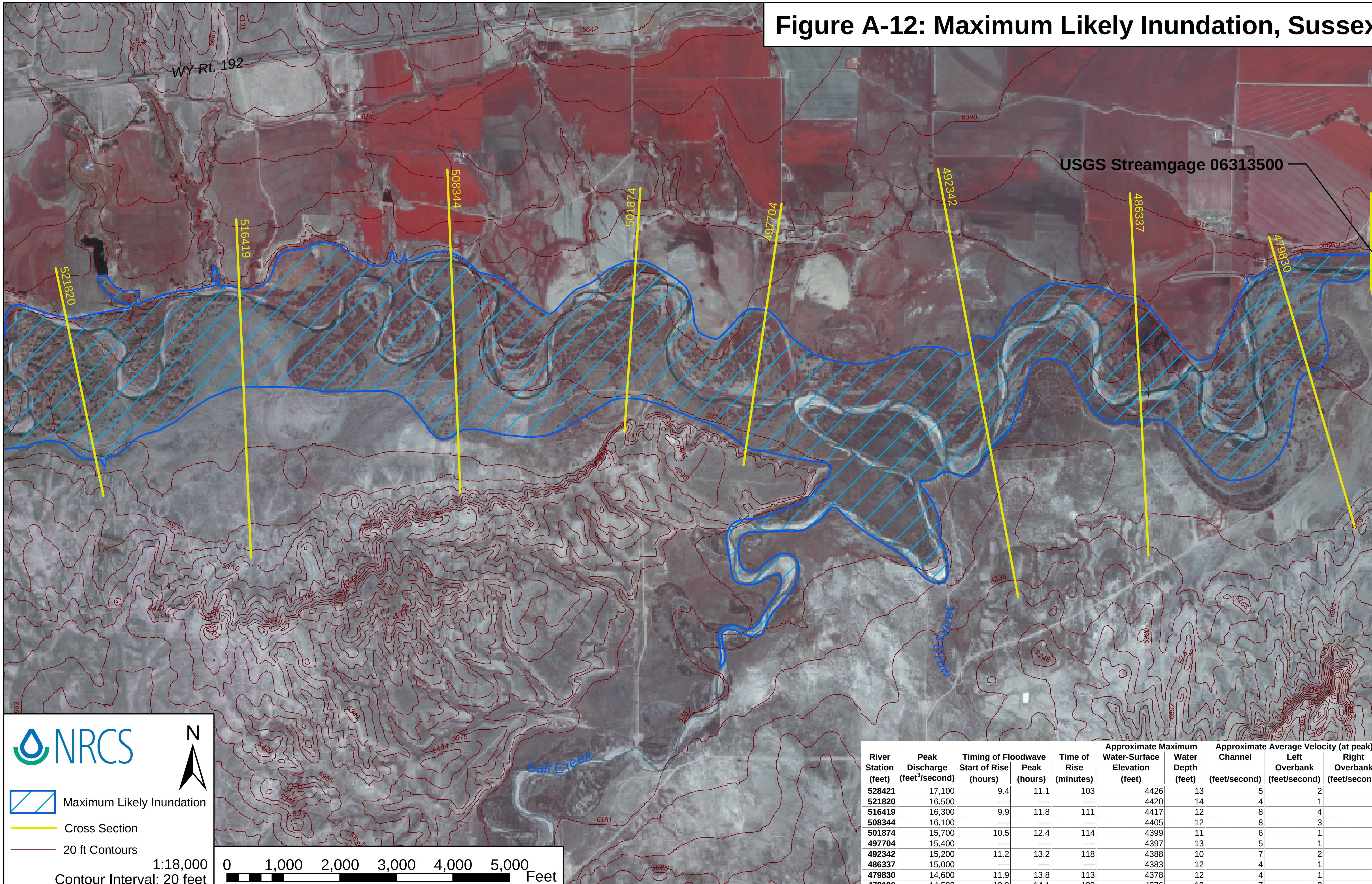
River Station (feet)	Peak Discharge (feet^3/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
619366	26,900	6.2	6.6	25	4586	14	6	3	4
617982	26,700	----	----	----	4585	19	5	2	3
617025	26,700	6.3	6.8	35	4583	21	7	1	3
Rt. 192									
616813	26,700	6.3	6.8	35	4577	16	21	1	9
615580	26,500	----	----	----	4570	12	8	3	2
613010	24,800	6.4	7.1	40	4566	13	7	3	3
612033	24,600	----	----	----	4566	13	4	2	2
611003	24,600	6.5	7.3	47	4565	14	5	2	2
608903	24,400	----	----	----	4560	11	8	3	3
607753	24,300	6.6	7.4	47	4559	12	5	2	2
604053	24,200	----	----	----	4553	17	15	3	8
602968	24,100	6.7	7.5	47	4550	13	6	3	3
599988	23,700	----	----	----	4543	15	11	1	3
598590	23,500	6.9	7.7	52	4542	17	4	1	2
596879	23,500	6.9	7.8	51	4536	14	10	3	3
596259	23,500	6.9	7.8	51	4534	16	8	3	4
593979	22,900	----	----	----	4530	16	5	2	2
591311	22,800	7.1	8.0	58	4524	13	13	5	5
587381	20,600	----	----	----	4514	15	4	1	2
583785	20,100	7.3	8.6	76	4512	17	6	3	2
581074	19,900	----	----	----	4509	15	9	4	2
575857	19,800	7.6	8.9	83	4499	15	12	5	5
572941	19,700	----	----	----	4490	15	10	4	2
569206	19,400	7.8	9.2	83	4484	16	9	3	3

Figure A-11: Maximum Likely Inundation, Powder River



River Station (feet)	Peak Discharge ($feet^3$/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
569206	19,400	7.8	9.2	83	4484	16	9	3	3
567836	19,100	----	----	----	4482	16	7	2	3
564594	19,000	8.0	9.5	90	4478	16	8	3	3
561830	18,900	----	----	----	4474	15	11	4	4
558961	18,800	8.1	9.7	92	4467	15	10	4	5
555391	18,100	----	----	----	4461	13	5	2	1
552249	17,700	8.5	10.2	103	4457	14	8	3	2
548153	17,700	----	----	----	4451	15	10	4	3
541172	17,500	8.9	10.6	101	4441	13	8	3	3
534651	17,300	----	----	----	4433	13	8	2	3
528421	17,100	9.4	11.1	103	4426	13	5	2	2

Figure A-12: Maximum Likely Inundation, Sussex



River Station (feet)	Peak Discharge (feet³/second)	Timing of Floodwave Start of Rise (hours)	Timing of Floodwave Peak (hours)	Time of Rise (minutes)	Approximate Maximum Water-Surface Elevation (feet)	Approximate Maximum Water Depth (feet)	Approximate Average Velocity (at peak) Channel (feet/second)	Approximate Average Velocity (at peak) Left Overbank (feet/second)	Approximate Average Velocity (at peak) Right Overbank (feet/second)
528421	17,100	9.4	11.1	103	4426	13	5	2	2
521820	16,500	----	----	----	4420	14	4	1	1
516419	16,300	9.9	11.8	111	4417	12	8	4	2
508344	16,100	----	----	----	4405	12	8	3	2
501874	15,700	10.5	12.4	114	4399	11	6	1	2
497704	15,400	----	----	----	4397	13	5	1	1
492342	15,200	11.2	13.2	118	4388	10	7	2	3
486337	15,000	----	----	----	4383	12	4	1	1
479830	14,600	11.9	13.8	113	4378	12	4	1	2
478190	14,500	12.0	14.1	122	4376	12	7	2	2

Appendix B
Peak Flow Characteristics Tables

Table B-1: Peak flow characteristics, station 999340 to 949054.

Stream	River Station	Reach Station	Reach	Peak Discharge (cfs)	Discharge Left (cfs)	Discharge Right (cfs)	Time to Initial Breach Flow (hours)	Time to Peak Discharge (hours)	Time of Rise (minutes)	Minimum Channel Elevation (ft)
N. F. Powder River	999340	23309.04	Canyon	154,000	41,600	64,700	0.0	0.5	28	8068
N. F. Powder River	998412	23026.20	Canyon	153,000	113,000	24,400	----	----	----	8061
N. F. Powder River	997419	22723.84	Canyon	152,000	18,400	110,000	----	----	----	8056
N. F. Powder River	996069	22312.41	Canyon	150,000	116,000	9,190	----	----	----	8038
N. F. Powder River	995232	22057.22	Canyon	150,000	55,500	45,300	----	----	----	8005
N. F. Powder River	994189	21739.34	Canyon	149,000	72,100	34,100	0.1	0.5	26	7972
N. F. Powder River	993429	21507.62	Canyon	148,000	19,900	72,900	----	----	----	7950
N. F. Powder River	992981	21371.17	Canyon	148,000	14,900	48,100	----	----	----	7940
N. F. Powder River	991981	21066.30	Canyon	147,000	73,900	9,620	----	----	----	7914
N. F. Powder River	991641	20963.03	Canyon	146,000	26,500	41,600	----	----	----	7907
N. F. Powder River	990710	20679.18	Canyon	145,000	97,900	14,700	0.1	0.6	26	7886
N. F. Powder River	990036	20473.56	Canyon	145,000	48,400	45,200	----	----	----	7874
N. F. Powder River	989349	20264.26	Canyon	142,000	81,300	13,600	----	----	----	7861
N. F. Powder River	989106	20190.28	Canyon	139,000	37,000	72,100	----	----	----	7856
N. F. Powder River	988868	20117.81	Canyon	139,000	91,500	8,650	----	----	----	7852
N. F. Powder River	988613	20039.99	Canyon	138,000	94,800	13,000	0.2	0.6	25	7847
N. F. Powder River	988271	19935.79	Canyon	138,000	59,000	30,800	----	----	----	7841
N. F. Powder River	987606	19732.39	Canyon	138,000	49,000	18,000	----	----	----	7826
N. F. Powder River	986921	19524.19	Canyon	136,000	72,000	32,700	----	----	----	7818
N. F. Powder River	986508	19398.16	Canyon	136,000	25,600	50,700	----	----	----	7808
N. F. Powder River	985556	19107.86	Canyon	135,000	36,300	14,600	0.2	0.6	24	7790
N. F. Powder River	984758	18864.52	Canyon	134,000	24,100	37,800	----	----	----	7776
N. F. Powder River	983673	18533.75	Canyon	133,000	16,400	37,000	----	----	----	7757
N. F. Powder River	982804	18268.83	Canyon	133,000	25,900	34,800	----	----	----	7742
N. F. Powder River	981769	17953.27	Canyon	131,000	79,300	12,600	----	----	----	7727
N. F. Powder River	981160	17767.52	Canyon	131,000	32,300	20,200	0.3	0.7	23	7710
N. F. Powder River	979898	17382.89	Canyon	129,000	55,600	4,820	----	----	----	7689
N. F. Powder River	979359	17218.65	Canyon	129,000	32,500	42,200	----	----	----	7677
N. F. Powder River	978599	16986.97	Canyon	128,000	11,400	11,100	----	----	----	7664
N. F. Powder River	977809	16746.08	Canyon	128,000	36,600	33,100	----	----	----	7644
N. F. Powder River	977237	16571.68	Canyon	128,000	6,860	23,100	0.4	0.7	23	7629
N. F. Powder River	976766	16428.21	Canyon	127,000	3,660	30,600	----	----	----	7611
N. F. Powder River	975967	16184.60	Canyon	127,000	65,100	7,430	----	----	----	7580
N. F. Powder River	975355	15997.96	Canyon	127,000	41,000	25,000	----	----	----	7546
N. F. Powder River	975069	15910.85	Canyon	127,000	24,700	29,900	----	----	----	7513
N. F. Powder River	974747	15812.75	Canyon	127,000	32,600	36,500	0.4	0.8	22	7481
N. F. Powder River	974369	15697.45	Canyon	127,000	23,500	41,200	----	----	----	7448
N. F. Powder River	974106	15617.18	Canyon	127,000	29,800	51,200	----	----	----	7414
N. F. Powder River	973907	15556.44	Canyon	127,000	32,500	45,800	----	----	----	7383
N. F. Powder River	973508	15434.80	Canyon	127,000	18,700	53,400	----	----	----	7349
N. F. Powder River	973153	15326.68	Canyon	127,000	37,300	42,000	0.4	0.8	22	7316
N. F. Powder River	972602	15158.81	Canyon	126,000	61,500	15,900	----	----	----	7283
N. F. Powder River	971977	14968.10	Canyon	126,000	22,600	46,700	----	----	----	7251
N. F. Powder River	971200	14731.06	Canyon	126,000	46,300	25,000	----	----	----	7218
N. F. Powder River	970239	14437.94	Canyon	125,000	16,000	41,600	----	----	----	7185
N. F. Powder River	969159	14108.81	Canyon	125,000	22,000	43,400	0.4	0.8	21	7152
N. F. Powder River	967978	13748.82	Canyon	125,000	47,600	28,800	----	----	----	7119
N. F. Powder River	966996	13449.55	Canyon	124,000	68,800	16,900	----	----	----	7086
N. F. Powder River	965708	13056.74	Canyon	124,000	33,700	22,100	----	----	----	7054
N. F. Powder River	964651	12734.50	Canyon	123,000	61,000	4,310	----	----	----	7021
N. F. Powder River	963612	12417.79	Canyon	123,000	31,800	40,300	0.5	0.9	19	6988
N. F. Powder River	962754	12156.28	Canyon	123,000	38,000	26,400	----	----	----	6955
N. F. Powder River	961958	11913.72	Canyon	122,000	59,400	4,370	----	----	----	6920
N. F. Powder River	960890	11588.16	Canyon	122,000	16,200	45,200	----	----	----	6889
N. F. Powder River	960095	11345.93	Canyon	122,000	34,500	24,800	----	----	----	6857
N. F. Powder River	958907	10983.80	Canyon	120,000	18,800	37,300	0.6	0.9	20	6824
N. F. Powder River	958287	10794.70	Canyon	120,000	49,000	9,500	----	----	----	6805
N. F. Powder River	957761	10634.46	Canyon	120,000	30,000	34,600	----	----	----	6791
N. F. Powder River	956956	10389.11	Canyon	117,000	17,400	27,200	----	----	----	6772
N. F. Powder River	956490	10247.05	Canyon	118,000	15,600	24,500	----	----	----	6758
N. F. Powder River	955830	10045.69	Canyon	118,000	282	53,900	0.6	0.9	19	6746
N. F. Powder River	955473	9936.73	Canyon	118,000	78,400	3,430	----	----	----	6739
N. F. Powder River	954751	9716.53	Canyon	118,000	25,700	57,700	----	----	----	6721
N. F. Powder River	954073	9509.92	Canyon	117,000	16,000	22,800	----	----	----	6707
N. F. Powder River	953404	9305.65	Canyon	117,000	363	60,500	----	----	----	6693
N. F. Powder River	952336	8980.19	Canyon	116,000	16,800	30,000	0.7	1.0	19	6660
N. F. Powder River	951105	8604.97	Canyon	116,000	10,100	60,500	----	----	----	6628
N. F. Powder River	950067	8288.59	Canyon	115,000	24,400	49,700	----	----	----	6594
N. F. Powder River	949054	7979.68	Canyon	115,000	28,300	25,700	----	----	----	6562

Table B-1: Peak flow characteristics

Stream	River Station	Water Surface Elevation (ft)	Maximum Channel Depth (ft)	Energy Grade Elevation (ft)	Energy Grade Slope (ft/ft)	Velocity: Channel (ft/s)	Velocity: Left Overbank (ft/s)	Velocity: Right Overbank (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude Number: Channel	Froude Number: Cross-Section
N. F. Powder River	999340	8096	28	8104	0.00785	29	16	20	7419	370	1.0	0.8
N. F. Powder River	998412	8098	36	8099	0.00135	15	10	8	15342	580	0.4	0.3
N. F. Powder River	997419	8095	39	8097	0.00200	19	9	12	12479	480	0.5	0.4
N. F. Powder River	996069	8076	38	8086	0.02940	40	22	10	6973	290	1.2	0.8
N. F. Powder River	995232	8047	42	8060	0.03641	42	21	16	6583	250	1.2	0.8
N. F. Powder River	994189	8016	44	8025	0.01839	35	18	11	8267	290	0.9	0.6
N. F. Powder River	993429	7993	42	8007	0.03900	43	18	17	6632	240	1.2	0.8
N. F. Powder River	992981	7978	38	7993	0.01524	41	12	10	8120	320	1.2	0.6
N. F. Powder River	991981	7963	50	7972	0.00736	34	13	6	9243	290	0.9	0.5
N. F. Powder River	991641	7954	48	7972	0.01987	45	15	11	7147	260	1.2	0.7
N. F. Powder River	990710	7937	51	7948	0.02947	43	21	10	6841	280	1.1	0.8
N. F. Powder River	990036	7914	40	7927	0.04180	39	24	16	6163	230	1.1	0.8
N. F. Powder River	989349	7899	39	7909	0.00748	36	20	6	7614	350	1.0	0.7
N. F. Powder River	989106	7899	43	7903	0.00269	23	11	12	10447	510	0.6	0.5
N. F. Powder River	988868	7900	48	7902	0.00113	16	7	2	19894	870	0.4	0.3
N. F. Powder River	988613	7899	52	7902	0.00132	18	12	3	14537	520	0.5	0.3
N. F. Powder River	988271	7894	53	7904	0.00943	40	14	8	9282	300	1.0	0.5
N. F. Powder River	987606	7874	48	7896	0.05862	47	28	16	4357	130	1.2	1.0
N. F. Powder River	986921	7861	44	7867	0.00598	28	15	12	8493	300	0.8	0.5
N. F. Powder River	986508	7858	50	7865	0.00642	32	10	9	10382	280	0.8	0.4
N. F. Powder River	985556	7840	50	7861	0.01907	45	16	10	5524	180	1.1	0.8
N. F. Powder River	984758	7826	50	7841	0.02159	41	16	13	6167	190	1.0	0.7
N. F. Powder River	983673	7804	47	7822	0.01364	44	12	11	6675	210	1.1	0.6
N. F. Powder River	982804	7792	50	7810	0.01859	44	15	12	6239	200	1.1	0.7
N. F. Powder River	981769	7782	55	7790	0.00757	37	13	7	9169	270	0.9	0.4
N. F. Powder River	981160	7766	57	7790	0.02644	50	16	12	5336	200	1.2	0.8
N. F. Powder River	979898	7746	57	7756	0.00629	34	11	5	7974	230	0.8	0.5
N. F. Powder River	979359	7737	60	7751	0.02408	43	13	12	7266	250	1.0	0.6
N. F. Powder River	978599	7713	49	7737	0.01242	44	9	7	5139	190	1.1	0.9
N. F. Powder River	977809	7705	61	7725	0.01979	52	12	15	6283	200	1.2	0.7
N. F. Powder River	977237	7688	58	7710	0.01895	42	8	15	4803	140	1.0	0.8
N. F. Powder River	976766	7673	62	7704	0.03526	51	7	15	4343	110	1.2	0.8
N. F. Powder River	975967	7633	53	7656	0.05802	54	22	12	4577	130	1.3	0.8
N. F. Powder River	975355	7594	48	7619	0.16435	50	28	25	3705	140	1.3	1.2
N. F. Powder River	975069	7557	43	7577	0.08098	43	23	24	4027	150	1.2	1.1
N. F. Powder River	974747	7530	49	7548	0.09547	45	22	23	4362	150	1.2	1.0
N. F. Powder River	974369	7493	46	7511	0.11110	42	21	24	4277	160	1.1	1.0
N. F. Powder River	974106	7459	46	7480	0.18986	48	25	29	3938	150	1.3	1.1
N. F. Powder River	973907	7433	50	7452	0.10335	48	23	25	4271	130	1.2	0.9
N. F. Powder River	973508	7395	46	7416	0.08233	49	18	24	4440	150	1.3	0.9
N. F. Powder River	973153	7370	54	7389	0.06039	51	20	19	5049	170	1.2	0.8
N. F. Powder River	972602	7341	58	7361	0.04345	53	18	13	5515	180	1.2	0.7
N. F. Powder River	971977	7308	57	7331	0.04211	55	14	17	5329	170	1.3	0.8
N. F. Powder River	971200	7277	59	7296	0.03832	51	17	14	5605	180	1.2	0.7
N. F. Powder River	970239	7237	52	7259	0.03803	49	12	17	5214	180	1.2	0.8
N. F. Powder River	969159	7199	48	7216	0.03966	42	15	23	4788	160	1.1	0.8
N. F. Powder River	967978	7156	37	7170	0.02411	36	25	23	4550	180	1.1	1.0
N. F. Powder River	966996	7136	50	7151	0.02106	41	27	10	5151	140	1.0	0.7
N. F. Powder River	965708	7104	50	7123	0.02731	43	25	13	4670	140	1.1	0.8
N. F. Powder River	964651	7070	49	7087	0.02624	44	20	8	4893	160	1.1	0.8
N. F. Powder River	963612	7036	48	7051	0.04209	43	22	18	4959	160	1.1	0.8
N. F. Powder River	962754	7001	46	7018	0.03611	43	21	15	4947	160	1.2	0.8
N. F. Powder River	961958	6973	53	6988	0.02156	40	19	7	5127	150	1.0	0.7
N. F. Powder River	960890	6936	47	6950	0.02346	41	15	14	5760	170	1.1	0.6
N. F. Powder River	960095	6911	54	6930	0.03044	46	15	14	5512	150	1.1	0.7
N. F. Powder River	958907	6894	69	6901	0.00650	29	9	8	8897	210	0.6	0.4
N. F. Powder River	958287	6870	65	6900	0.06498	56	28	13	3600	91	1.2	0.9
N. F. Powder River	957761	6845	54	6863	0.03226	47	15	15	5477	150	1.1	0.6
N. F. Powder River	956956	6822	50	6842	0.01889	45	10	12	5670	170	1.1	0.6
N. F. Powder River	956490	6818	60	6835	0.00764	40	7	8	7190	160	0.9	0.4
N. F. Powder River	955830	6802	56	6823	0.04661	47	3	19	4250	90	1.1	0.7
N. F. Powder River	955473	6783	45	6789	0.00671	26	16	5	7039	240	0.7	0.6
N. F. Powder River	954751	6768	46	6778	0.02151	40	11	19	6172	220	1.0	0.6
N. F. Powder River	954073	6755	48	6768	0.00826	35	7	12	6232	190	0.9	0.6
N. F. Powder River	953404	6742	49	6756	0.02369	41	3	14	5681	160	1.0	0.6
N. F. Powder River	952336	6707	47	6729	0.02964	46	16	14	4642	130	1.2	0.7
N. F. Powder River	951105	6673	46	6691	0.03979	46	11	24	4489	180	1.2	0.9
N. F. Powder River	950067	6638	44	6650	0.02902	38	24	15	5384	170	1.0	0.7
N. F. Powder River	949054	6606	44	6625	0.07249	45	24	14	4314	210	1.2	1.0

Table B-2: Peak flow characteristics, station 948456 to 857599.

Stream	River Station	Reach Station	Reach	Peak Discharge (cfs)	Discharge Left (cfs)	Discharge Right (cfs)	Time to Initial Breach Flow (hours)	Time to Peak Discharge (hours)	Time of Rise (minutes)	Minimum Channel Elevation (ft)
N. F. Powder River	948456	7797.39	Canyon	115,000	35,700	31,300	----	----	----	6528
N. F. Powder River	947873	7619.65	Canyon	115,000	54,500	19,600	0.7	1.0	18	6496
N. F. Powder River	946670	7252.74	Canyon	114,000	28,500	51,400	----	----	----	6464
N. F. Powder River	946100	7078.91	Canyon	114,000	17,800	34,600	----	----	----	6430
N. F. Powder River	945302	6835.70	Canyon	114,000	54,800	17,100	----	----	----	6398
N. F. Powder River	944835	6693.37	Canyon	114,000	39,800	23,700	----	----	----	6363
N. F. Powder River	944175	6492.27	Canyon	114,000	33,400	27,300	0.8	1.1	17	6332
N. F. Powder River	943067	6154.56	Canyon	113,000	37,800	21,400	----	----	----	6299
N. F. Powder River	942206	5892.07	Canyon	113,000	70,600	4,020	----	----	----	6281
N. F. Powder River	941466	5666.58	Canyon	113,000	22,100	55,000	----	----	----	6266
N. F. Powder River	940719	5438.93	Canyon	113,000	19,700	63,600	----	----	----	6248
N. F. Powder River	940156	5267.43	Canyon	113,000	54,000	30,900	0.8	1.1	17	6233
N. F. Powder River	939472	5058.93	Canyon	113,000	60,100	8,350	----	----	----	6213
N. F. Powder River	938930	4893.78	Canyon	113,000	18,800	36,000	----	----	----	6201
N. F. Powder River	937952	4595.65	Canyon	112,000	7,730	71,600	----	----	----	6184
N. F. Powder River	937086	4331.68	Canyon	112,000	52,500	23,200	----	----	----	6168
N. F. Powder River	935825	3947.35	Canyon	112,000	60,000	23,000	0.9	1.1	15	6149
N. F. Powder River	934798	3634.27	Canyon	110,000	27,500	57,700	----	----	----	6137
N. F. Powder River	933707	3301.66	Canyon	109,000	42,300	25,600	----	----	----	6103
N. F. Powder River	933061	3104.62	Canyon	109,000	7,940	62,300	----	----	----	6035
N. F. Powder River	932387	2899.22	Canyon	109,000	40,400	19,200	----	----	----	6003
N. F. Powder River	932119	2817.54	Canyon	109,000	20,800	52,400	0.9	1.2	15	5969
N. F. Powder River	931453	2614.44	Canyon	109,000	52,300	18,200	----	----	----	5938
N. F. Powder River	930477	2316.90	Canyon	109,000	24,100	41,700	----	----	----	5905
N. F. Powder River	929470	2009.93	Canyon	109,000	43,200	24,100	----	----	----	5873
N. F. Powder River	928494	1712.41	Canyon	108,000	43,600	26,000	----	----	----	5840
N. F. Powder River	927310	1351.53	Canyon	108,000	37,200	28,400	1.0	1.2	14	5814
N. F. Powder River	927134	1297.84	Canyon	108,000	58,600	23,000	----	----	----	5812
N. F. Powder River	926910	1229.55	Canyon	108,000	70,500	12,000	----	----	----	5807
N. F. Powder River	925861	909.67	Canyon	108,000	29,500	36,500	1.0	1.2	14	5775
N. F. Powder River	924481	488.89	Canyon	107,000	37,600	22,300	----	----	----	5742
N. F. Powder River	923480	183.86	Canyon	107,000	15,800	50,800	----	----	----	5726
N. F. Powder River	923130	77.06	Canyon	107,000	71,500	11,500	----	----	----	5721
N. F. Powder River	922894	5.18	Canyon	107,000	77,300	3,060	1.0	1.3	15	5717
N. F. Powder River	922894	51974.60	Canyon to Rt 191	96,100	75,000	1,730	1.0	1.3	15	5717
N. F. Powder River	921872	51662.92	Canyon to Rt 191	95,300	6,730	56,600	----	----	----	5704
N. F. Powder River	921080	51421.44	Canyon to Rt 191	94,900	35,100	10,100	1.1	1.2	10	5694
N. F. Powder River	920487	51240.54	Canyon to Rt 191	95,000	8,560	42,400	----	----	----	5684
N. F. Powder River	919543	50952.85	Canyon to Rt 191	95,000	61,700	3,830	1.1	1.4	18	5670
N. F. Powder River	918220	50549.55	Canyon to Rt 191	94,900	26,400	53,100	----	----	----	5652
N. F. Powder River	916781	50110.78	Canyon to Rt 191	94,800	28,800	52,200	1.1	1.4	17	5630
N. F. Powder River	914829	49515.67	Canyon to Rt 191	91,000	40,500	30,900	----	----	----	5611
N. F. Powder River	913099	48988.20	Canyon to Rt 191	83,500	25,500	4,450	1.3	1.5	17	5596
N. F. Powder River	912212	48717.85	Canyon to Rt 191	83,500	31,100	38,700	----	----	----	5589
N. F. Powder River	910320	48141.04	Canyon to Rt 191	83,400	678	57,300	1.3	1.6	16	5572
N. F. Powder River	908877	47701.25	Canyon to Rt 191	83,400	40,600	27,600	----	----	----	5560
N. F. Powder River	908386	47551.49	Canyon to Rt 191	83,400	54,800	6,530	1.3	1.6	15	5557
N. F. Powder River	907220	47196.09	Canyon to Rt 191	83,300	44,700	6,250	----	----	----	5551
N. F. Powder River	905916	46798.40	Canyon to Rt 191	83,100	16,000	38,600	1.4	1.6	14	5540
N. F. Powder River	904539	46378.69	Canyon to Rt 191	83,000	71,200	329	----	----	----	5531
N. F. Powder River	902199	45664.28	Canyon to Rt 191	83,000	60,500	7,070	1.4	1.7	13	5515
N. F. Powder River	899851	44948.32	Canyon to Rt 191	82,900	18,900	52,800	----	----	----	5501
N. F. Powder River	897543	44244.61	Canyon to Rt 191	82,800	5,060	65,900	1.5	1.7	13	5482
N. F. Powder River	894739	43389.83	Canyon to Rt 191	82,700	3,570	63,100	----	----	----	5464
N. F. Powder River	891476	42395.30	Canyon to Rt 191	82,600	27,200	45,000	1.6	1.8	12	5441
N. F. Powder River	889145	41684.87	Canyon to Rt 191	82,400	74,600	316	----	----	----	5425
N. F. Powder River	886780	40964.00	Canyon to Rt 191	82,400	26,500	39,600	1.7	1.8	9	5408
N. F. Powder River	883614	39998.99	Canyon to Rt 191	82,100	42,300	32,100	----	----	----	5390
N. F. Powder River	876747	37905.98	Canyon to Rt 191	81,500	3,290	63,600	1.8	1.9	8	5366
N. F. Powder River	873963	37057.32	Canyon to Rt 191	80,500	38,900	33,300	----	----	----	5353
N. F. Powder River	870792	36090.90	Canyon to Rt 191	78,100	72,100	145	1.8	2.0	12	5340
N. F. Powder River	867148	34980.37	Canyon to Rt 191	77,800	6,670	63,300	----	----	----	5322
N. F. Powder River	862459	33551.10	Canyon to Rt 191	77,300	54,800	16,500	2.0	2.1	9	5301
N. F. Powder River	859756	32727.17	Canyon to Rt 191	76,500	61,700	830	----	----	----	5290
N. F. Powder River	857223	31955.27	Canyon to Rt 191	76,200	53,100	13,100	2.0	2.2	10	5273
N. F. Powder River	852736	30587.69	Canyon to Rt 191	76,000	7,600	58,600	----	----	----	5256
N. F. Powder River	856073	29570.49	Canyon to Rt 191	75,100	34,200	34,000	2.1	2.3	8	5243
N. F. Powder River	860746	28146.30	Canyon to Rt 191	73,900	32,900	31,200	----	----	----	5230
N. F. Powder River	857599	27187.06	Canyon to Rt 191	71,600	49,300	8,630	2.2	2.4	9	5215

Table B-2: Peak flow characteristics

Stream	River Station	Water Surface Elevation (ft)	Maximum Channel Depth (ft)	Energy Grade Elevation (ft)	Energy Grade Slope (ft/ft)	Velocity Channel (ft/s)	Velocity Left Overbank (ft/s)	Velocity Right Overbank (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude Number Channel	Froude Number Cross-Section
N. F. Powder River	948456	6568	39	6581	0.06214	38	24	17	4536	180	1.1	0.9
N. F. Powder River	947873	6539	43	6553	0.02505	40	27	15	4341	170	1.1	0.9
N. F. Powder River	946670	6503	39	6517	0.05788	40	24	26	3998	160	1.1	1.0
N. F. Powder River	946100	6475	44	6493	0.03305	41	18	26	3812	150	1.1	1.1
N. F. Powder River	945302	6439	42	6455	0.07884	41	27	21	3885	150	1.1	1.0
N. F. Powder River	944835	6408	44	6425	0.04769	42	27	23	3698	130	1.1	1.0
N. F. Powder River	944175	6378	47	6398	0.04238	45	26	21	3743	140	1.2	1.0
N. F. Powder River	943067	6345	46	6359	0.01164	40	18	12	5226	190	1.1	0.7
N. F. Powder River	942206	6328	48	6347	0.03051	45	30	10	3664	150	1.2	1.1
N. F. Powder River	941466	6302	35	6317	0.03203	39	22	29	3841	170	1.2	1.1
N. F. Powder River	940719	6282	34	6290	0.02587	32	16	19	5485	220	1.0	0.7
N. F. Powder River	940156	6267	33	6275	0.01973	29	20	20	5121	250	0.9	0.9
N. F. Powder River	939472	6250	37	6261	0.02100	31	23	15	4542	190	0.9	0.9
N. F. Powder River	938930	6236	35	6251	0.02306	38	19	23	4055	170	1.2	1.0
N. F. Powder River	937952	6220	36	6228	0.01206	31	11	18	5740	270	0.9	0.7
N. F. Powder River	937086	6203	36	6212	0.02169	33	17	16	5641	230	1.0	0.7
N. F. Powder River	935825	6180	30	6188	0.01384	32	19	17	5492	250	1.1	0.8
N. F. Powder River	934798	6169	32	6173	0.00718	25	13	15	6986	290	0.8	0.6
N. F. Powder River	933707	6142	39	6158	0.11552	39	27	24	3703	130	1.1	1.0
N. F. Powder River	933061	6078	42	6093	0.03645	39	16	28	3768	150	1.1	1.0
N. F. Powder River	932387	6041	37	6056	0.15724	40	22	22	3915	190	1.2	1.1
N. F. Powder River	932119	6007	38	6021	0.04538	39	21	28	3802	150	1.1	1.0
N. F. Powder River	931453	5979	41	5994	0.02830	40	27	21	3740	150	1.1	1.0
N. F. Powder River	930477	5948	44	5964	0.03478	42	23	25	3742	140	1.1	1.0
N. F. Powder River	929470	5912	40	5929	0.03906	42	26	24	3651	150	1.2	1.1
N. F. Powder River	928494	5878	38	5892	0.02506	37	25	23	3907	140	1.1	0.9
N. F. Powder River	927310	5847	33	5865	0.05218	42	30	25	3398	150	1.3	1.2
N. F. Powder River	927134	5848	35	5852	0.00632	24	14	5	9496	590	0.7	0.5
N. F. Powder River	926910	5840	33	5850	0.02204	31	25	18	4349	180	1.0	0.9
N. F. Powder River	925861	5812	37	5824	0.02477	35	21	22	4236	200	1.0	1.0
N. F. Powder River	924481	5782	41	5792	0.01472	30	20	16	4795	180	0.8	0.8
N. F. Powder River	923480	5755	29	5770	0.11002	37	22	28	3600	180	1.2	1.2
N. F. Powder River	923130	5745	25	5749	0.00656	25	13	10	7833	480	0.9	0.6
N. F. Powder River	922894	5740	23	5746	0.01198	32	14	12	6544	560	1.2	0.8
N. F. Powder River	922894	5751	34	5752	0.00163	14	7	5	12479	570	0.5	0.3
N. F. Powder River	921872	5748	44	5750	0.00193	20	5	7	11426	310	0.5	0.2
N. F. Powder River	921080	5744	50	5749	0.00247	24	7	6	8627	220	0.6	0.3
N. F. Powder River	920487	5745	61	5747	0.00054	13	3	4	16274	370	0.3	0.2
N. F. Powder River	919543	5697	27	5702	0.00856	29	10	6	8024	550	1.0	0.5
N. F. Powder River	918220	5665	13	5668	0.02308	28	10	9	9167	1100	1.5	0.6
N. F. Powder River	916781	5643	13	5644	0.00860	17	8	10	9699	1000	0.9	0.6
N. F. Powder River	914829	5635	23	5635	0.00204	13	4	6	15537	1000	0.5	0.2
N. F. Powder River	913099	5605	9	5618	0.01312	15	34	5	2032	540	1.0	1.6
N. F. Powder River	912212	5605	17	5608	0.00940	22	11	8	8190	740	1.0	0.5
N. F. Powder River	910320	5589	17	5592	0.00896	21	7	8	8670	740	1.0	0.5
N. F. Powder River	908877	5582	22	5585	0.00536	21	10	10	7633	540	0.8	0.5
N. F. Powder River	908386	5576	19	5581	0.01102	25	14	10	5524	490	1.1	0.8
N. F. Powder River	907220	5571	20	5572	0.00279	14	6	5	9230	710	0.6	0.3
N. F. Powder River	905916	5567	26	5567	0.00077	9	4	4	15727	890	0.3	0.2
N. F. Powder River	904539	5546	15	5548	0.01513	25	11	8	7210	810	1.2	0.7
N. F. Powder River	902199	5530	15	5533	0.01094	21	11	11	7019	820	1.0	0.7
N. F. Powder River	899851	5514	14	5516	0.00984	20	9	10	8170	970	1.0	0.6
N. F. Powder River	897543	5497	15	5499	0.00746	18	9	9	8731	1000	0.9	0.6
N. F. Powder River	894739	5480	16	5483	0.01132	23	9	11	7100	700	1.1	0.7
N. F. Powder River	891476	5456	15	5457	0.00421	13	6	8	10745	1400	0.6	0.5
N. F. Powder River	889145	5439	14	5441	0.00537	15	9	5	8608	890	0.7	0.5
N. F. Powder River	886780	5421	14	5424	0.01098	20	10	13	6481	880	1.0	0.8
N. F. Powder River	883614	5402	12	5404	0.00537	13	7	8	10414	1400	0.7	0.5
N. F. Powder River	876747	5380	14	5381	0.00638	15	6	9	8851	1100	0.8	0.6
N. F. Powder River	873963	5369	16	5370	0.00219	10	6	6	12190	1200	0.5	0.4
N. F. Powder River	870792	5354	14	5356	0.00412	12	9	4	8753	910	0.6	0.5
N. F. Powder River	867148	5334	12	5336	0.00898	15	5	9	8494	1300	0.9	0.6
N. F. Powder River	862459	5314	14	5315	0.00365	11	7	6	11364	1600	0.6	0.5
N. F. Powder River	859756	5303	15	5305	0.00952	18	9	8	7609	1100	0.9	0.7
N. F. Powder River	857223	5287	14	5289	0.01377	20	9	11	7432	1500	1.1	0.8
N. F. Powder River	852736	5270	14	5271	0.00371	12	8	6	11277	1800	0.6	0.5
N. F. Powder River	856073	5257	14	5258	0.00351	12	7	6	11267	1500	0.6	0.4
N. F. Powder River	860746	5246	15	5247	0.00641	17	9	9	7931	900	0.8	0.5
N. F. Powder River	857599	5237	21	5238	0.00552	17	8	6	8330	1200	0.7	0.6

Table B-3: Peak flow characteristics, station 857164 to 619366.

Stream	River Station	Reach Station	Reach	Peak Discharge (cfs)	Discharge Left (cfs)	Discharge Right (cfs)	Time to Initial Breach Flow (hours)	Time to Peak Discharge (hours)	Time of Rise (minutes)	Minimum Channel Elevation (ft)
N. F. Powder River		27108.00	Canyon to Rt 191	Mayoworth Bridge						
N. F. Powder River	857164	27054.54	Canyon to Rt 191	----	----	----	----	----	----	5215
N. F. Powder River	853262	25865.20	Canyon to Rt 191	----	----	----	----	----	----	5199
N. F. Powder River	848645	24457.95	Canyon to Rt 191	58,700	39,400	8,770	2.3	2.6	21	5179
N. F. Powder River	844639	23236.53	Canyon to Rt 191	58,400	23,300	26,800	----	----	----	5158
N. F. Powder River	840152	21868.96	Canyon to Rt 191	58,200	52,500	41	2.5	2.8	17	5146
N. F. Powder River	834345	20098.94	Canyon to Rt 191	58,100	20,900	30,000	----	----	----	5121
N. F. Powder River	826994	17858.33	Canyon to Rt 191	57,700	26,200	22,300	2.6	2.9	16	5099
N. F. Powder River	823299	16732.05	Canyon to Rt 191	57,500	19,400	26,200	----	----	----	5090
N. F. Powder River	817976	15109.48	Canyon to Rt 191	57,300	31,400	16,700	2.7	3.0	15	5075
N. F. Powder River	809413	12499.37	Canyon to Rt 191	57,000	308	50,700	----	----	----	5060
N. F. Powder River	802608	10425.27	Canyon to Rt 191	55,900	24,600	22,400	2.9	3.1	13	5042
N. F. Powder River	801212	9999.91	Canyon to Rt 191	55,600	47,100	2,330	----	----	----	5037
N. F. Powder River	797293	8805.54	Canyon to Rt 191	55,400	43,700	294	3.0	3.2	13	5033
N. F. Powder River	792520	7350.62	Canyon to Rt 191	55,100	38,200	7,060	----	----	----	5019
N. F. Powder River	787842	5924.67	Canyon to Rt 191	54,600	34,800	86	3.1	3.3	11	5005
N. F. Powder River	782688	4353.85	Canyon to Rt 191	53,600	4,110	26,200	----	----	----	4987
N. F. Powder River	777692	2831.21	Canyon to Rt 191	53,400	39,800	4,860	3.1	3.5	28	4972
N. F. Powder River	774637	1899.93	Canyon to Rt 191	51,000	14,400	29,600	----	----	----	4962
N. F. Powder River	772442	1230.80	Canyon to Rt 191	49,300	8,290	27,300	3.3	3.7	28	4947
N. F. Powder River		1199.00	Canyon to Rt 191	Rt. 191 Bridge						
N. F. Powder River	772148	1141.28	Canyon to Rt 191	45,600	8,080	14,000	3.3	3.7	28	4947
N. F. Powder River	771287	878.94	Canyon to Rt 191	49,600	13,200	31,700	----	----	----	4942
N. F. Powder River	768422	5.67	Canyon to Rt 191	49,400	3,130	35,500	3.4	3.8	21	4930
N. F. Powder River	768422	52294.53	Rt 191 to Confluence	49,000	11,500	30,900	3.5	3.8	16	4930
N. F. Powder River	767200	51922.08	Rt 191 to Confluence	48,900	28,900	1,680	----	----	----	4927
N. F. Powder River	763354	50749.87	Rt 191 to Confluence	48,800	18,300	5,550	3.6	3.9	15	4917
N. F. Powder River	757557	48982.98	Rt 191 to Confluence	48,400	37,900	215	----	----	----	4896
N. F. Powder River	754793	48140.58	Rt 191 to Confluence	48,300	19,700	17,600	3.7	4.0	15	4889
N. F. Powder River	750530	46841.27	Rt 191 to Confluence	48,200	11,300	23,300	----	----	----	4880
N. F. Powder River	740967	43926.44	Rt 191 to Confluence	47,800	13,100	26,900	3.9	4.1	12	4863
N. F. Powder River	733683	41706.41	Rt 191 to Confluence	46,800	21,300	15,300	----	----	----	4848
N. F. Powder River	728060	39992.68	Rt 191 to Confluence	46,400	26,700	9,160	4.1	4.4	20	4837
N. F. Powder River	722244	38220.07	Rt 191 to Confluence	46,000	24,900	14,800	----	----	----	4828
N. F. Powder River	716035	36327.53	Rt 191 to Confluence	42,000	8,730	26,300	4.2	4.5	15	4811
N. F. Powder River	714052	35722.99	Rt 191 to Confluence	42,000	4,270	35,000	----	----	----	4806
N. F. Powder River	712107	35130.03	Rt 191 to Confluence	37,600	24,200	1,300	4.3	4.5	13	4802
N. F. Powder River	708191	33936.39	Rt 191 to Confluence	37,600	2,300	29,200	----	----	----	4794
N. F. Powder River	705950	33253.47	Rt 191 to Confluence	37,500	26,400	3,740	4.4	4.8	24	4788
N. F. Powder River	700433	31571.89	Rt 191 to Confluence	37,200	30,500	133	----	----	----	4777
N. F. Powder River	693699	29519.54	Rt 191 to Confluence	36,500	26,700	6,660	4.5	4.9	25	4767
N. F. Powder River	690884	28661.64	Rt 191 to Confluence	36,400	31,700	1,990	4.6	5.0	24	4767
N. F. Powder River		28611.43	Rt 191 to Confluence	I-25 Bridge						
N. F. Powder River	690314	28487.96	Rt 191 to Confluence	36,400	25,100	1,230	4.6	5.0	24	4763
N. F. Powder River	686036	27184.17	Rt 191 to Confluence	36,200	14,700	7,620	----	----	----	4753
N. F. Powder River	683426	26388.64	Rt 191 to Confluence	36,200	27,000	979	4.7	5.1	23	4745
N. F. Powder River	680812	25592.01	Rt 191 to Confluence	35,800	31,700	1,510	----	----	----	4736
N. F. Powder River	679139	25082.05	Rt 191 to Confluence	35,400	26,400	3,710	4.8	5.2	24	4728
N. F. Powder River	678294	24824.52	Rt 191 to Confluence	35,300	9,860	19,700	4.8	5.2	25	4725
N. F. Powder River		24787.49	Rt 191 to Confluence	Rt. 196 Bridge						
N. F. Powder River	677994	24733.28	Rt 191 to Confluence	34,700	10,200	20,400	4.8	5.2	25	4723
N. F. Powder River	676878	24393.07	Rt 191 to Confluence	34,500	31,000	80	----	----	----	4722
N. F. Powder River	674456	23654.93	Rt 191 to Confluence	34,900	144	26,800	4.9	5.4	29	4711
N. F. Powder River	672529	23067.71	Rt 191 to Confluence	34,700	249	26,600	----	----	----	4704
N. F. Powder River	670696	22508.96	Rt 191 to Confluence	34,500	13,100	17,000	5.0	5.4	26	4698
N. F. Powder River	667221	21449.85	Rt 191 to Confluence	33,600	255	32,300	----	----	----	4695
N. F. Powder River	663196	20222.99	Rt 191 to Confluence	33,500	26,800	282	5.2	5.6	24	4678
N. F. Powder River	660530	19410.42	Rt 191 to Confluence	33,300	27,700	1,520	----	----	----	4671
N. F. Powder River	658288	18726.99	Rt 191 to Confluence	33,000	27,700	114	5.4	5.7	21	4663
N. F. Powder River	654066	17440.02	Rt 191 to Confluence	32,500	22,600	5,080	----	----	----	4654
N. F. Powder River	648192	15649.56	Rt 191 to Confluence	32,200	1,550	25,100	5.6	5.9	19	4643
N. F. Powder River	642174	13815.33	Rt 191 to Confluence	31,700	12,600	14,400	----	----	----	4633
N. F. Powder River	638397	12664.21	Rt 191 to Confluence	31,000	21,000	5,770	5.8	6.1	19	4625
N. F. Powder River	634285	11410.99	Rt 191 to Confluence	30,900	403	25,400	----	----	----	4614
N. F. Powder River	631087	10436.15	Rt 191 to Confluence	28,600	754	26,200	5.9	6.3	26	4606
N. F. Powder River	626622	9075.09	Rt 191 to Confluence	28,500	20,600	277	----	----	----	4595
N. F. Powder River	624416	8402.74	Rt 191 to Confluence	28,500	23,100	161	6.0	6.5	28	4585
N. F. Powder River	621879	7629.41	Rt 191 to Confluence	28,500	5,600	15,200	----	----	----	4577
N. F. Powder River	619366	6863.35	Rt 191 to Confluence	26,900	3,080	20,300	6.2	6.6	25	4571

Table B-3: Peak flow characteristics

Stream	River Station	Water Surface Elevation (ft)	Maximum Channel Depth (ft)	Energy Grade Elevation (ft)	Energy Grade Slope (ft/ft)	Velocity Channel (ft/s)	Velocity Left Overbank (ft/s)	Velocity Right Overbank (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude Number Channel	Froude Number Cross-Section
N. F. Powder River		Mayoworth Bridge										
N. F. Powder River	857164	5234	19	5236	0.00770	21	8	8	7874	1300	0.9	0.7
N. F. Powder River	853262	5223	24	5223	0.00002	----	----	----	----	----	----	----
N. F. Powder River	848645	5192	13	5194	0.00840	16	10	10	5648	810	0.9	0.7
N. F. Powder River	844639	5173	15	5174	0.00459	13	6	7	8221	1000	0.7	0.4
N. F. Powder River	840152	5155	11	5157	0.00682	12	8	4	7033	1200	0.8	0.6
N. F. Powder River	834345	5135	14	5136	0.00683	16	6	7	8441	2000	0.8	0.6
N. F. Powder River	826994	5116	16	5117	0.00621	16	8	7	7052	1300	0.8	0.6
N. F. Powder River	823299	5105	16	5108	0.00838	20	7	11	5646	990	0.9	0.8
N. F. Powder River	817976	5091	16	5092	0.00410	13	8	5	7673	1200	0.6	0.5
N. F. Powder River	809413	5072	12	5073	0.00587	14	5	7	7776	1200	0.7	0.5
N. F. Powder River	802608	5060	19	5062	0.00330	13	6	7	7869	900	0.6	0.4
N. F. Powder River	801212	5056	19	5057	0.00299	13	7	6	7313	750	0.6	0.4
N. F. Powder River	797293	5049	16	5051	0.00623	16	7	4	7154	1400	0.8	0.6
N. F. Powder River	792520	5034	15	5035	0.00505	14	6	4	8435	1800	0.7	0.5
N. F. Powder River	787842	5022	17	5023	0.00537	15	6	4	6948	1300	0.7	0.6
N. F. Powder River	782688	5003	16	5005	0.00487	14	3	5	8490	2700	0.7	0.6
N. F. Powder River	777692	4985	14	4986	0.00602	13	5	3	9874	3200	0.7	0.5
N. F. Powder River	774637	4975	13	4975	0.00262	9	4	4	11867	2800	0.5	0.4
N. F. Powder River	772442	4971	24	4972	0.00146	11	3	4	11158	2000	0.4	0.3
N. F. Powder River		Rt. 191 Bridge										
N. F. Powder River	772148	4968	20	4972	0.00770	23	9	5	4419	1000	0.9	0.9
N. F. Powder River	771287	4953	10	4954	0.00355	10	6	7	7381	1000	0.6	0.4
N. F. Powder River	768422	4945	15	4947	0.00926	19	5	11	4544	790	0.9	0.8
N. F. Powder River	768422	4951	21	4951	0.00093	8	3	5	10688	1300	0.3	0.3
N. F. Powder River	767200	4945	18	4948	0.00645	18	8	8	4909	850	0.8	0.7
N. F. Powder River	763354	4934	17	4936	0.00491	15	5	8	6331	1500	0.7	0.7
N. F. Powder River	757557	4915	19	4916	0.00515	16	6	5	6879	830	0.7	0.4
N. F. Powder River	754793	4905	16	4907	0.00655	18	7	11	5244	860	0.8	0.7
N. F. Powder River	750530	4896	17	4898	0.00624	16	5	7	6522	1500	0.8	0.6
N. F. Powder River	740967	4879	16	4880	0.00446	13	4	7	7417	1600	0.6	0.5
N. F. Powder River	733683	4865	17	4866	0.00568	15	7	6	5943	1000	0.7	0.6
N. F. Powder River	728060	4854	17	4855	0.00504	14	8	4	6028	1200	0.7	0.6
N. F. Powder River	722244	4842	14	4843	0.00628	13	6	8	6809	1500	0.7	0.6
N. F. Powder River	716035	4828	18	4829	0.00082	7	4	4	10197	1000	0.3	0.2
N. F. Powder River	714052	4828	22	4828	0.00035	5	2	3	13184	980	0.2	0.2
N. F. Powder River	712107	4825	22	4825	0.00087	8	3	4	8858	1000	0.3	0.3
N. F. Powder River	708191	4810	16	4811	0.00113	7	3	4	8450	990	0.3	0.3
N. F. Powder River	705950	4802	14	4803	0.00373	12	6	6	5742	930	0.6	0.5
N. F. Powder River	700433	4793	15	4793	0.00366	11	5	4	6924	1500	0.6	0.4
N. F. Powder River	693699	4788	21	4789	0.00047	5	3	2	11261	1100	0.2	0.2
N. F. Powder River	690884	4788	21	4788	0.00018	4	2	2	16359	1300	0.1	0.1
N. F. Powder River		I-25 Bridge										
N. F. Powder River	690314	4777	14	4777	0.00195	9	4	4	7864	1400	0.4	0.3
N. F. Powder River	686036	4770	17	4772	0.00429	15	7	6	4209	570	0.7	0.6
N. F. Powder River	683426	4759	14	4760	0.00665	15	7	6	4759	970	0.8	0.6
N. F. Powder River	680812	4747	12	4748	0.00338	10	5	6	6578	1200	0.6	0.4
N. F. Powder River	679139	4744	16	4744	0.00173	9	4	5	7783	1200	0.4	0.3
N. F. Powder River	678294	4743	17	4743	0.00085	7	3	4	9595	1300	0.3	0.2
N. F. Powder River		Rt. 196 Bridge										
N. F. Powder River	677994	4738	15	4738	0.00049	5	3	3	11347	1200	0.2	0.2
N. F. Powder River	676878	4737	15	4737	0.00098	6	3	2	9871	1400	0.3	0.2
N. F. Powder River	674456	4724	13	4725	0.00348	10	4	5	5972	1100	0.6	0.4
N. F. Powder River	672529	4717	13	4718	0.00314	10	3	6	5721	920	0.5	0.4
N. F. Powder River	670696	4711	13	4712	0.00334	10	6	5	6128	1100	0.5	0.4
N. F. Powder River	667221	4707	17	4707	0.00027	3	1	2	15046	1600	0.2	0.1
N. F. Powder River	663196	4692	14	4693	0.00538	13	5	5	5790	980	0.7	0.4
N. F. Powder River	660530	4683	12	4684	0.00425	11	5	7	6359	1200	0.6	0.4
N. F. Powder River	658288	4676	12	4676	0.00425	10	5	4	6529	1400	0.6	0.4
N. F. Powder River	654066	4669	15	4669	0.00221	8	4	4	7522	1300	0.4	0.3
N. F. Powder River	648192	4655	12	4655	0.00263	9	4	4	7112	1400	0.5	0.4
N. F. Powder River	642174	4649	16	4649	0.00208	9	5	3	7110	1100	0.4	0.3
N. F. Powder River	638397	4642	16	4642	0.00113	7	4	5	7747	1000	0.3	0.3
N. F. Powder River	634285	4628	13	4629	0.00461	12	5	5	5479	1300	0.6	0.5
N. F. Powder River	631087	4623	17	4623	0.00026	4	2	2	13581	1400	0.2	0.1
N. F. Powder River	626622	4611	16	4613	0.00648	17	7	5	3330	570	0.8	0.6
N. F. Powder River	624416	4601	16	4601	0.00305	10	4	4	5931	1100	0.5	0.4
N. F. Powder River	621879	4590	14	4591	0.00346	11	3	6	5053	970	0.6	0.4
N. F. Powder River	619366	4586	14	4586	0.00093	6	3	4	7251	920	0.3	0.2

Table B-4: Peak flow characteristics, station 617982 to 478190.

Stream	River Station	Reach Station	Reach	Peak Discharge (cfs)	Discharge Left (cfs)	Discharge Right (cfs)	Time to Initial Breach Flow (hours)	Time to Peak Discharge (hours)	Time of Rise (minutes)	Minimum Channel Elevation (ft)
N. F. Powder River	617982	6441.64	Rt 191 to Confluence	26,700	15,900	7,110	----	----	----	4565
N. F. Powder River	617025	6149.91	Rt 191 to Confluence	26,700	19,100	323	6.3	6.8	35	4562
N. F. Powder River		6117.50	Rt 191 to Confluence	Rt. 192 Bridge						
N. F. Powder River	616813	6085.25	Rt 191 to Confluence	26,700	13,100	3,690	6.3	6.8	35	4561
Powder River	615580	5709.33	Rt 191 to Confluence	26,500	16,800	55	----	----	----	4558
Powder River	613010	4926.12	Rt 191 to Confluence	24,800	17,900	730	6.4	7.1	40	4553
Powder River	612033	4628.24	Rt 191 to Confluence	24,600	16,200	2,820	----	----	----	4552
Powder River	611003	4314.20	Rt 191 to Confluence	24,600	18,700	220	6.5	7.3	47	4551
Powder River	608903	3673.30	Rt 191 to Confluence	24,400	344	15,500	----	----	----	4548
Powder River	607753	3323.47	Rt 191 to Confluence	24,300	102	20,000	6.6	7.4	47	4547
Powder River	604053	2194.79	Rt 191 to Confluence	24,200	7,120	3,350	----	----	----	4536
Powder River	602968	1864.90	Rt 191 to Confluence	24,100	7,910	7,690	6.7	7.5	47	4536
Powder River	599988	956.58	Rt 191 to Confluence	23,700	62	10,300	----	----	----	4529
Powder River	598590	530.54	Rt 191 to Confluence	23,500	37	16,400	6.9	7.7	52	4525
Powder River	596879	9.01	Rt 191 to Confluence	23,500	14,400	128	6.9	7.8	51	4522
Powder River	596259	104144.70	Confluence to Hoe Ranch	23,500	9,520	3,290	6.9	7.8	51	4519
Powder River	593979	103450.00	Confluence to Hoe Ranch	22,900	278	16,400	----	----	----	4514
Powder River	591311	102636.70	Confluence to Hoe Ranch	22,800	1,940	7,110	7.1	8.0	58	4511
Powder River	587381	101438.80	Confluence to Hoe Ranch	20,600	2,840	12,600	----	----	----	4498
Powder River	583785	100342.90	Confluence to Hoe Ranch	20,100	491	10,700	7.3	8.6	76	4495
Powder River	581074	99516.50	Confluence to Hoe Ranch	19,900	1,870	6,510	----	----	----	4493
Powder River	575857	97926.49	Confluence to Hoe Ranch	19,800	2,850	1,950	7.6	8.9	83	4484
Powder River	572941	97037.64	Confluence to Hoe Ranch	19,700	5,910	388	----	----	----	4476
Powder River	569206	95899.08	Confluence to Hoe Ranch	19,400	4,660	3,210	7.8	9.2	83	4468
Powder River	567836	95481.48	Confluence to Hoe Ranch	19,100	4,690	4,890	----	----	----	4466
Powder River	564594	94493.45	Confluence to Hoe Ranch	19,000	5,930	2,580	8.0	9.5	90	4463
Powder River	561830	93650.94	Confluence to Hoe Ranch	18,900	4,260	941	----	----	----	4459
Powder River	558961	92776.54	Confluence to Hoe Ranch	18,800	5,270	1,110	8.1	9.7	92	4453
Powder River	555391	91688.56	Confluence to Hoe Ranch	18,100	9,060	4,110	----	----	----	4448
Powder River	552249	90730.97	Confluence to Hoe Ranch	17,700	2,380	6,140	8.5	10.2	103	4443
Powder River	548153	89482.60	Confluence to Hoe Ranch	17,700	1,690	4,030	----	----	----	4436
Powder River	541172	87354.82	Confluence to Hoe Ranch	17,500	2,010	6,340	8.9	10.6	101	4427
Powder River	534651	85367.27	Confluence to Hoe Ranch	17,300	1,650	6,730	----	----	----	4419
Powder River	528421	83468.42	Confluence to Hoe Ranch	17,100	8,730	2,460	9.4	11.1	103	4413
Powder River	521820	81456.58	Confluence to Hoe Ranch	16,500	107	11,800	----	----	----	4406
Powder River	516419	79810.50	Confluence to Hoe Ranch	16,300	1,070	6,660	9.9	11.8	111	4405
Powder River	508344	77349.16	Confluence to Hoe Ranch	16,100	546	8,530	----	----	----	4394
Powder River	501874	75377.02	Confluence to Hoe Ranch	15,700	1,630	9,080	10.5	12.4	114	4388
Powder River	497704	74106.11	Confluence to Hoe Ranch	15,400	1,310	8,880	----	----	----	4384
Powder River	492342	72471.85	Confluence to Hoe Ranch	15,200	8,490	1,310	11.2	13.2	118	4378
Powder River	486337	70641.51	Confluence to Hoe Ranch	15,000	8,260	2,660	----	----	----	4371
Powder River	479830	68658.36	Confluence to Hoe Ranch	14,600	225	10,200	11.9	13.8	113	4366
Powder River	478190	68158.42	Confluence to Hoe Ranch	14,500	371	7,440	12.0	14.1	122	4364

Table B-4: Peak flow characteristics

Stream	River Station	Water Surface Elevation (ft)	Maximum Channel Depth (ft)	Energy Grade Elevation (ft)	Energy Grade Slope (ft/ft)	Velocity Channel (ft/s)	Velocity Left Overbank (ft/s)	Velocity Right Overbank (ft/s)	Flow Area (sq ft)	Top Width (ft)	Froude Number Channel	Froude Number Cross-Section
N. F. Powder River	617982	4585	19	4585	0.00046	5	2	3	10046	1100	0.2	0.2
N. F. Powder River	617025	4583	21	4583	0.00086	7	1	3	14029	1900	0.3	0.1
N. F. Powder River		Rt. 192 Bridge										
N. F. Powder River	616813	4577	16	4579	0.01165	21	1	9	10590	1800	1.0	0.2
Powder River	615580	4570	12	4571	0.00215	8	3	2	7458	2100	0.4	0.3
Powder River	613010	4566	13	4567	0.00143	7	3	3	7810	1200	0.4	0.2
Powder River	612033	4566	13	4566	0.00048	4	2	2	10525	1400	0.2	0.2
Powder River	611003	4565	14	4565	0.00071	5	2	2	9082	1100	0.3	0.2
Powder River	608903	4560	11	4560	0.00225	8	3	3	6214	1100	0.5	0.3
Powder River	607753	4559	12	4559	0.00068	5	2	2	9003	1500	0.3	0.2
Powder River	604053	4553	17	4555	0.00655	15	3	8	3485	1200	0.8	0.7
Powder River	602968	4550	13	4550	0.00173	6	3	3	7139	1800	0.4	0.3
Powder River	599988	4543	15	4544	0.00368	11	1	3	4572	1200	0.6	0.5
Powder River	598590	4542	17	4542	0.00047	4	1	2	9968	1300	0.2	0.2
Powder River	596879	4536	14	4537	0.00250	10	3	3	6085	1300	0.5	0.3
Powder River	596259	4534	16	4535	0.00136	8	3	4	5647	810	0.4	0.3
Powder River	593979	4530	16	4530	0.00047	5	2	2	10578	1600	0.2	0.2
Powder River	591311	4524	13	4526	0.00420	13	5	5	2949	550	0.6	0.6
Powder River	587381	4514	15	4514	0.00038	4	1	2	9982	1400	0.2	0.1
Powder River	583785	4512	17	4512	0.00081	6	3	2	6588	880	0.3	0.2
Powder River	581074	4509	15	4509	0.00180	9	4	2	5158	1300	0.4	0.3
Powder River	575857	4499	15	4501	0.00306	12	5	5	2264	280	0.6	0.5
Powder River	572941	4490	15	4492	0.00261	10	4	2	2872	330	0.5	0.4
Powder River	569206	4484	16	4485	0.00147	9	3	3	3941	510	0.4	0.3
Powder River	567836	4482	16	4482	0.00119	7	2	3	5541	1200	0.3	0.3
Powder River	564594	4478	16	4479	0.00133	8	3	3	4460	570	0.4	0.3
Powder River	561830	4474	15	4476	0.00270	11	4	4	2686	490	0.5	0.5
Powder River	558961	4467	15	4469	0.00261	10	4	5	2923	560	0.5	0.5
Powder River	555391	4461	13	4461	0.00055	5	2	1	9178	1600	0.2	0.2
Powder River	552249	4457	14	4457	0.00155	8	3	2	4779	870	0.4	0.3
Powder River	548153	4451	15	4452	0.00226	10	4	3	3142	530	0.5	0.4
Powder River	541172	4441	13	4441	0.00187	8	3	3	4301	760	0.4	0.3
Powder River	534651	4433	13	4433	0.00178	8	2	3	4786	1400	0.4	0.3
Powder River	528421	4426	13	4426	0.00078	5	2	2	8114	1700	0.3	0.2
Powder River	521820	4420	14	4420	0.00040	4	1	1	10817	2400	0.2	0.1
Powder River	516419	4417	12	4418	0.00245	8	4	2	4318	1700	0.5	0.4
Powder River	508344	4405	12	4406	0.00192	8	3	2	6189	2300	0.4	0.3
Powder River	501874	4399	11	4399	0.00116	6	1	2	7117	1900	0.3	0.2
Powder River	497704	4397	13	4397	0.00067	5	1	1	8224	1900	0.3	0.2
Powder River	492342	4388	10	4388	0.00184	7	2	3	5782	2100	0.4	0.3
Powder River	486337	4383	12	4383	0.00061	4	1	1	9083	2100	0.2	0.1
Powder River	479830	4378	12	4378	0.00055	4	1	2	6795	1600	0.2	0.2
Powder River	478190	4376	12	4377	0.00	7	2	2	4969	1700	0.4	0.3

Appendix C
Streamgage Frequency Analyses

06311000: NORTH FORK POWDER RIVER NEAR HAZELTON, WY

06311500: NORTH FORK POWDER RIVER NEAR MAYOWORTH, WY

06311400: NF POWDER RIVER BELOW PASS CREEK, NR MAYOWORTH, WY

06312500: POWDER RIVER NEAR KAYCEE, WY

06313500: POWDER RIVER AT SUSSEX, WY

NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *DullKnife Breach Analysis*
Streamgage: # *USGS 06311000 NORTH FORK POWDER RIVER NEAR HAZELTON, WY*
Date: *11/23/2004* **Performed By:** *Steve Yochum*

Without Generalized Skew

Average: 5.6317
Standard Deviation: 0.40903972
Skew Coefficient(1): 0.2926212

Length of systematic record: 57
Number of historic peaks: 0
Length of Data Record: 57
Length of Historic Record:(5) ----

With Generalized Skew

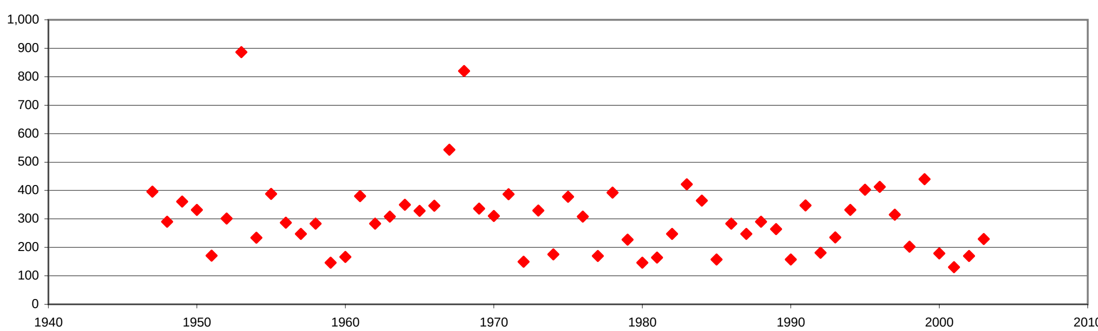
Generalized Skew Coefficient(3):
Variance of Generalized Skew(3):
A: -0.306590
B: 0.863918
station skew: 0.292621
MSE Station Skew: 0.1097477
Weighted skew coefficient(1): 0

Recurrence Interval(2) (years)	Percent Chance	K-Value	Ln(Q)	Peak(4) Discharge (cfs)	90% Confidence Interval Upper (cfs)	Lower (cfs)
200	0.5	2.849	6.7971	895	1,130	750
100	1	2.539	6.6701	788	977	670
50	2	2.207	6.5345	688	834	594
25	4	1.847	6.3871	594	704	521
10	10	1.308	6.1669	477	547	427
5	20	0.824	5.9689	391	438	355
2	50	-0.049	5.6118	274	299	250
1.25	80	-0.853	5.2829	197	217	176
1.05	95	-1.557	4.9947	148	166	127
200	0.5	2.576	6.6854	----	----	----
100	1	2.326	6.5831	----	----	----
50	2	2.054	6.4719	----	----	----
25	4	1.751	6.3479	----	----	----
10	10	1.282	6.1561	----	----	----
5	20	0.842	5.9761	----	----	----
2	50	0.000	5.6317	----	----	----
1.25	80	-0.842	5.2873	----	----	----
1.05	95	-1.645	4.9588	----	----	----

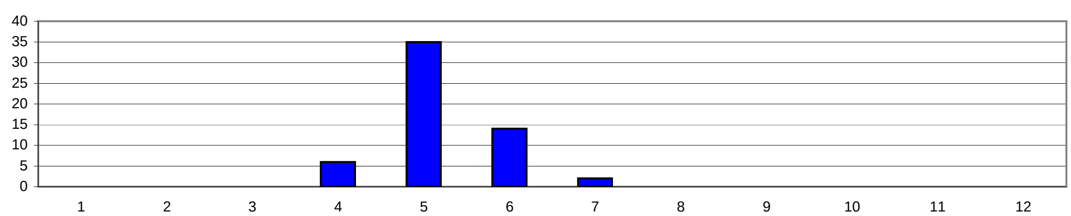
(1) Station and generalized skews must be between -2.00 and +3.00 in this spreadsheet.
(2) Considering the relatively short length of most gage records, less frequent peak estimates need to be used with considerable care.
(3) Computed one of four ways (see "generalized skew coefficient" worksheet): Mean and variance (standard deviation ^{2}) of station skews coefficients in region; skew isolines drawn on a map or regions; skew prediction equations; read from Plate 1 of Bulletin 17B (reproduced in this spreadsheet), with MSE Generalized Skew = 0.302.
(4) Results are automatically rounded to three significant figures, the dominant number of significant figures in the K-Value table.
(5) Historic frequency analysis assumes that intervening years reflect systematic record.

Comments:

Data Plot:



Peak Timing:



NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *DullKnife Breach Analysis*
Streamgage: *# USGS 06311000 NORTH FORK POWDER RIVER NEAR HAZELTON, WY*
Date: *11/23/2004* **Performed By:** *Steve Yochum*

Input Data

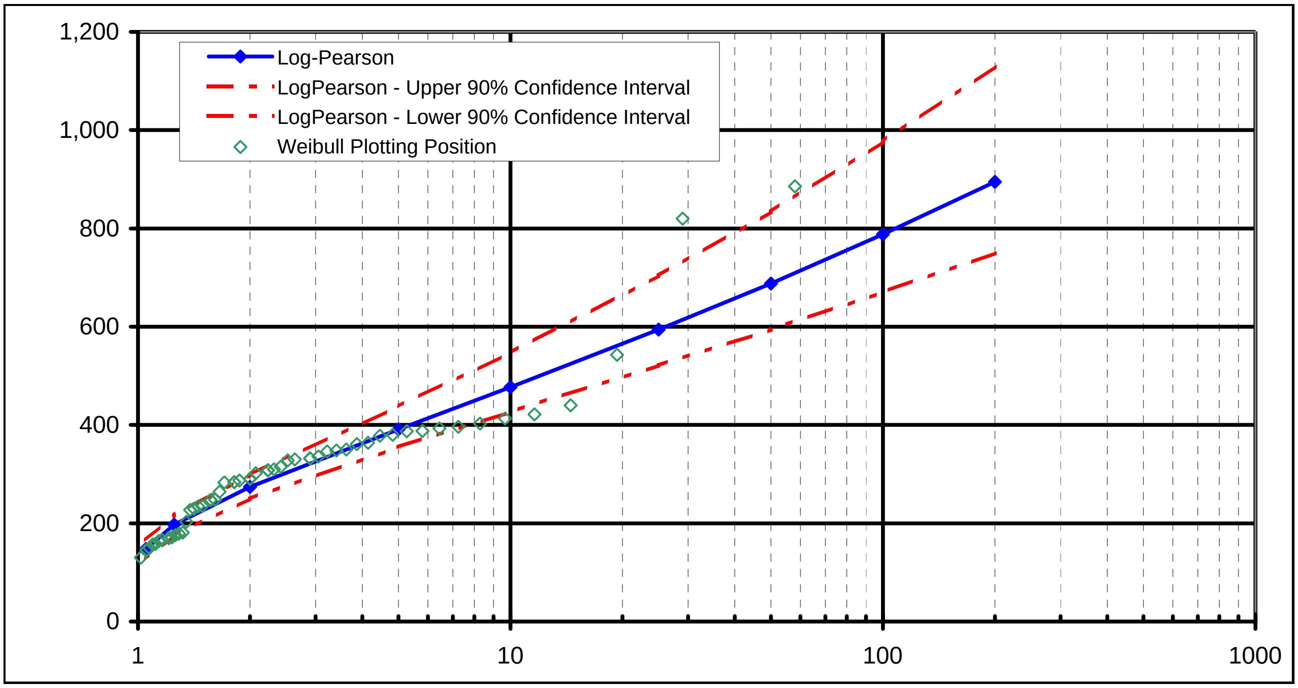
Station ID: *06311000* **Latitude, Longitude:** *44°01'40" 107°04'49"*
Drainage Area (mi^2): *24.5* **County:** *Johnson*
Number of low outliers eliminated: *0* **State:** *Wyoming*

	Date	Discharge (cfs)	Historic?	Outlier?		Date	Discharge (cfs)	Historic?	Outlier?		Date	Discharge (cfs)	Historic?	Outlier?
1	05/05/1947	396	n	n	51	06/08/1997	315	n	n	101	----	----	n	n
2	05/20/1948	290	n	n	52	05/20/1998	203	n	n	102	----	----	n	n
3	06/06/1949	361	n	n	53	05/01/1999	440	n	n	103	----	----	n	n
4	05/23/1950	332	n	n	54	05/16/2000	179	n	n	104	----	----	n	n
5	05/18/1951	171	n	n	55	04/29/2001	130	n	n	105	----	----	n	n
6	05/03/1952	302	n	n	56	05/19/2002	170	n	n	106	----	----	n	n
7	06/15/1953	886	n	y	57	05/22/2003	230	n	n	107	----	----	n	n
8	05/10/1954	234	n	n	58	----	----	n	n	108	----	----	n	n
9	06/15/1955	388	n	n	59	----	----	n	n	109	----	----	n	n
10	05/24/1956	287	n	n	60	----	----	n	n	110	----	----	n	n
11	06/10/1957	247	n	n	61	----	----	n	n	111	----	----	n	n
12	05/07/1958	284	n	n	62	----	----	n	n	112	----	----	n	n
13	06/03/1959	146	n	n	63	----	----	n	n	113	----	----	n	n
14	04/23/1960	166	n	n	64	----	----	n	n	114	----	----	n	n
15	05/10/1961	380	n	n	65	----	----	n	n	115	----	----	n	n
16	05/08/1962	284	n	n	66	----	----	n	n	116	----	----	n	n
17	06/01/1963	308	n	n	67	----	----	n	n	117	----	----	n	n
18	05/18/1964	350	n	n	68	----	----	n	n	118	----	----	n	n
19	06/24/1965	328	n	n	69	----	----	n	n	119	----	----	n	n
20	05/07/1966	346	n	n	70	----	----	n	n	120	----	----	n	n
21	06/05/1967	543	n	n	71	----	----	n	n	121	----	----	n	n
22	06/08/1968	820	n	n	72	----	----	n	n	122	----	----	n	n
23	04/23/1969	336	n	n	73	----	----	n	n	123	----	----	n	n
24	05/20/1970	310	n	n	74	----	----	n	n	124	----	----	n	n
25	05/29/1971	387	n	n	75	----	----	n	n	125	----	----	n	n
26	06/02/1972	150	n	n	76	----	----	n	n	126	----	----	n	n
27	05/18/1973	330	n	n	77	----	----	n	n	127	----	----	n	n
28	05/09/1974	176	n	n	78	----	----	n	n	128	----	----	n	n
29	07/03/1975	378	n	n	79	----	----	n	n	129	----	----	n	n
30	05/19/1976	308	n	n	80	----	----	n	n	130	----	----	n	n
31	05/10/1977	170	n	n	81	----	----	n	n	131	----	----	n	n
32	06/09/1978	393	n	n	82	----	----	n	n	132	----	----	n	n
33	05/23/1979	227	n	n	83	----	----	n	n	133	----	----	n	n
34	05/27/1980	146	n	n	84	----	----	n	n	134	----	----	n	n
35	05/17/1981	164	n	n	85	----	----	n	n	135	----	----	n	n
36	06/17/1982	247	n	n	86	----	----	n	n	136	----	----	n	n
37	05/27/1983	422	n	n	87	----	----	n	n	137	----	----	n	n
38	05/23/1984	364	n	n	88	----	----	n	n	138	----	----	n	n
39	05/03/1985	158	n	n	89	----	----	n	n	139	----	----	n	n
40	05/04/1986	283	n	n	90	----	----	n	n	140	----	----	n	n
41	04/27/1987	248	n	n	91	----	----	n	n	141	----	----	n	n
42	05/13/1988	290	n	n	92	----	----	n	n	142	----	----	n	n
43	04/23/1989	264	n	n	93	----	----	n	n	143	----	----	n	n
44	05/24/1990	157	n	n	94	----	----	n	n	144	----	----	n	n
45	05/18/1991	348	n	n	95	----	----	n	n	145	----	----	n	n
46	07/21/1992	181	n	n	96	----	----	n	n	146	----	----	n	n
47	05/28/1993	235	n	n	97	----	----	n	n	147	----	----	n	n
48	04/21/1994	332	n	n	98	----	----	n	n	148	----	----	n	n
49	06/03/1995	403	n	n	99	----	----	n	n	149	----	----	n	n
50	05/16/1996	413	n	n	100	----	----	n	n	150	----	----	n	n

Project: *DullKnife Breach Analysis*
Streamgage: *# USGS 06311000 NORTH FORK POWDER RIVER NEAR HAZELTON, WY*
Date: *11/23/2004* **Performed By:** *Steve Yochum*

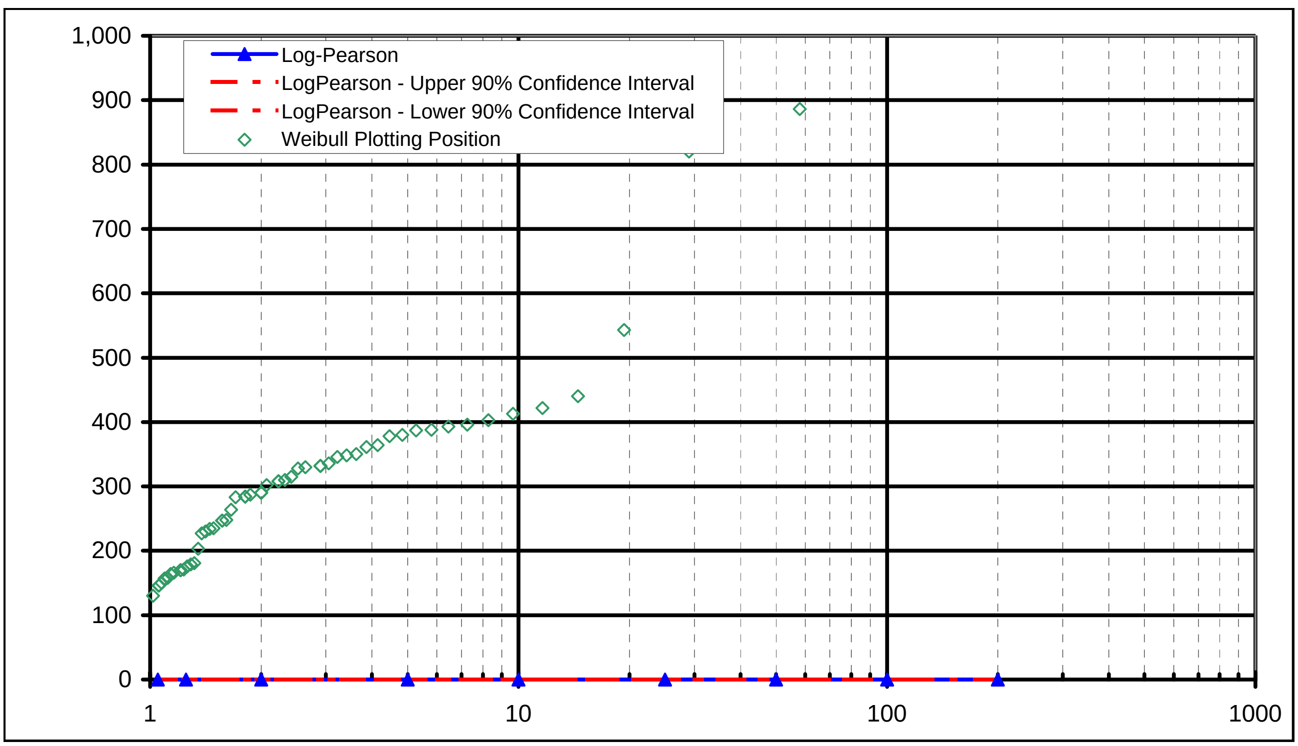
Discharge-Frequency, with Gage Skew

 # USGS 06311000 NORTH FORK POWDER RIVER NEAR HAZELTON, WY



Discharge-Frequency, with Generalized Skew

 # USGS 06311000 NORTH FORK POWDER RIVER NEAR HAZELTON, WY



NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *Dullknife Dam Breach Analysis*
Streamgage: # *USGS 06311500 NORTH FORK POWDER RIVER NEAR MAYOWORTH, WY*
Date: *11/19/2004* **Performed By:** *Steve Yochum*

Without Generalized Skew

Average: 6.0454
Standard Deviation: 0.56105364
Skew Coefficient[1]**:** -0.0859432

Length of systematic record: 33
Number of historic peaks: 0
Length of Data Record: 33
Length of Historic Record:[5] ----

With Generalized Skew

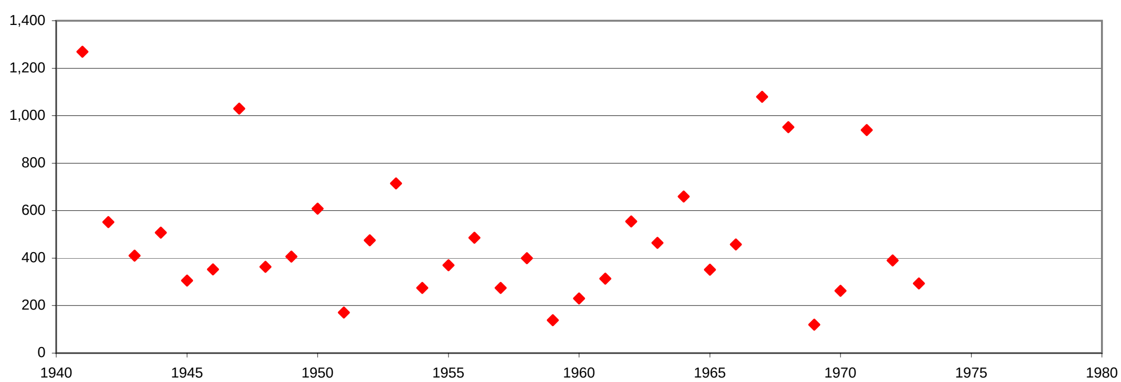
Generalized Skew Coefficient[3]**:**
Variance of Generalized Skew[3]**:**
A: -0.323125
B: 0.917655
station skew: -0.085943
MSE Station Skew: 0.15887614
Weighted skew coefficient[1]**:** 0

Recurrence Interval[2] (years)	Percent Chance	K-Value	Ln(Q)	Peak[4] Discharge (cfs)	90% Confidence Interval Upper (cfs)	Lower (cfs)
200	0.5	2.495	7.4453	1,710	2,560	1,290
100	1	2.262	7.3147	1,500	2,180	1,160
50	2	2.008	7.1717	1,300	1,830	1,020
25	4	1.721	7.0109	1,110	1,510	888
10	10	1.272	6.7589	862	1,110	710
5	20	0.845	6.5197	678	840	571
2	50	0.015	6.0536	426	502	361
1.25	80	-0.837	5.5759	264	313	213
1.05	95	-1.669	5.1089	165	206	122
200	0.5	2.576	7.4906	----	----	----
100	1	2.326	7.3504	----	----	----
50	2	2.054	7.1978	----	----	----
25	4	1.751	7.0278	----	----	----
10	10	1.282	6.7646	----	----	----
5	20	0.842	6.5178	----	----	----
2	50	0.000	6.0454	----	----	----
1.25	80	-0.842	5.5730	----	----	----
1.05	95	-1.645	5.1224	----	----	----

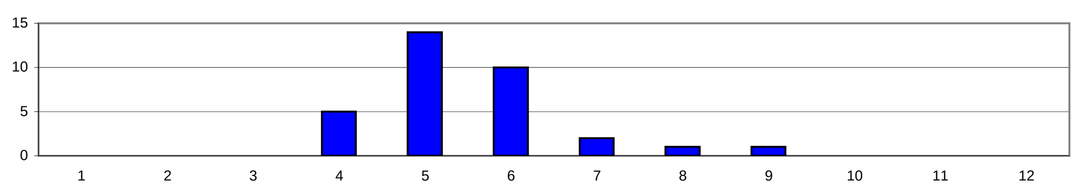
(1) Station and generalized skews must be between -2.00 and +3.00 in this spreadsheet.
(2) Considering the relatively short length of most gage records, less frequent peak estimates need to be used with considerable care.
(3) Computed one of four ways (see "generalized skew coefficient" worksheet): Mean and variance (standard deviation ^{2}) of station skews coefficients in region; skew isolines drawn on a map or regions; skew prediction equations; read from Plate 1 of Bulletin 17B (reproduced in this spreadsheet), with MSE Generalized Skew = 0.302.
(4) Results are automatically rounded to three significant figures, the dominant number of significant figures in the K-Value table.
(5) Historic frequency analysis assumes that intervening years reflect systematic record.

Comments: *This is a historic gage that used to be located adjacent to the Hat Ranch's primary buildings.*

Data Plot:



Peak Timing:



NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *Dullknife Dam Breach Analysis*
Streamgage: *# USGS 06311500 NORTH FORK POWDER RIVER NEAR MAYOWORTH, WY*
Date: *11/19/2004* **Performed By:** *Steve Yochum*

Input Data

Station ID: *06311500* **Latitude, Longitude:** *43,53,50* *106,52,40*
Drainage Area (mi^2): *106* **County:** *Johnson*
Number of low outliers eliminated: *0* **State:** *WY*

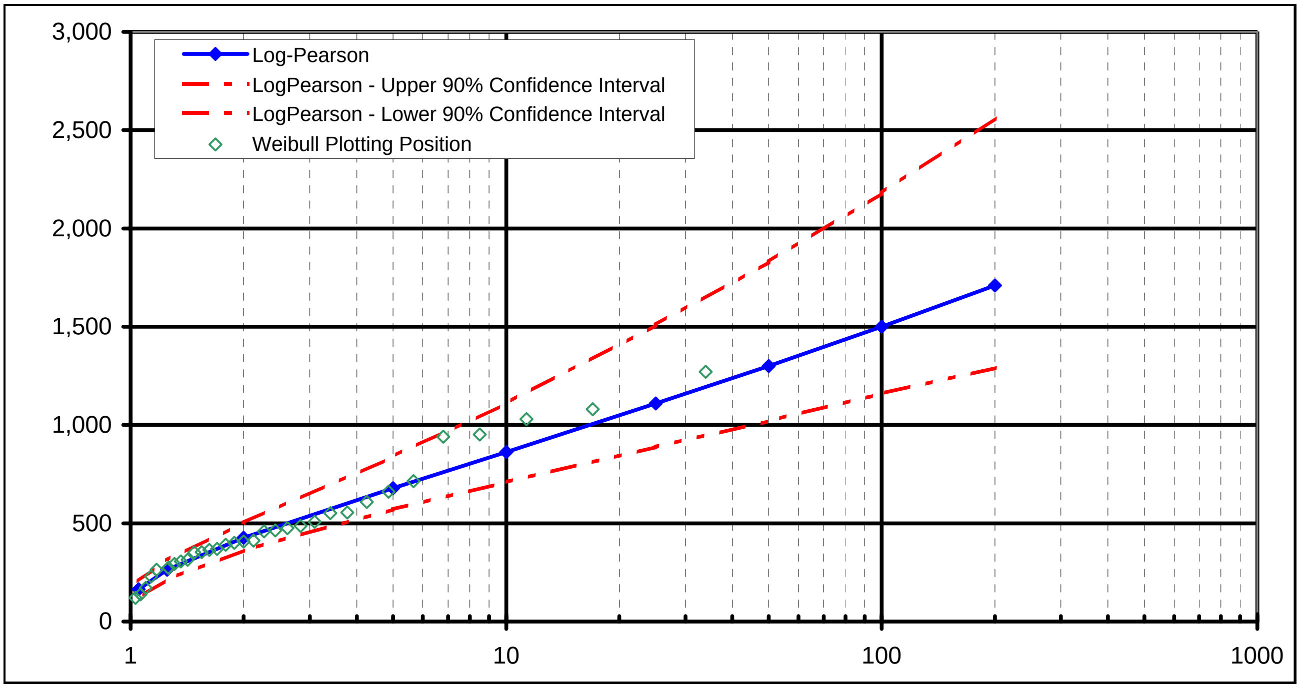
	Date	Discharge (cfs)	Historic?	Outlier?
1	08/11/1941	1,270	n	n
2	04/14/1942	552	n	n
3	06/12/1943	411	n	n
4	05/17/1944	507	n	n
5	05/06/1945	306	n	n
6	04/18/1946	353	n	n
7	05/03/1947	1,030	n	n
8	05/20/1948	364	n	n
9	06/06/1949	406	n	n
10	05/17/1950	608	n	n
11	05/19/1951	171	n	n
12	04/27/1952	475	n	n
13	06/15/1953	715	n	n
14	05/10/1954	274	n	n
15	06/15/1955	370	n	n
16	06/14/1956	486	n	n
17	06/11/1957	274	n	n
18	05/07/1958	400	n	n
19	06/22/1959	139	n	n
20	04/24/1960	230	n	n
21	05/11/1961	314	n	n
22	04/24/1962	554	n	n
23	09/21/1963	464	n	n
24	07/11/1964	660	n	n
25	06/25/1965	351	n	n
26	05/08/1966	458	n	n
27	07/11/1967	1,080	n	n
28	06/09/1968	952	n	n
29	05/21/1969	120	n	n
30	05/21/1970	263	n	n
31	05/30/1971	940	n	n
32	06/09/1972	390	n	n
33	05/16/1973	293	n	n
34	----	----	n	n
35	----	----	n	n
36	----	----	n	n
37	----	----	n	n
38	----	----	n	n
39	----	----	n	n
40	----	----	n	n
41	----	----	n	n
42	----	----	n	n
43	----	----	n	n
44	----	----	n	n
45	----	----	n	n
46	----	----	n	n
47	----	----	n	n
48	----	----	n	n
49	----	----	n	n
50	----	----	n	n

	Date	Discharge (cfs)	Historic?	Outlier?
51	----	----	n	n
52	----	----	n	n
53	----	----	n	n
54	----	----	n	n
55	----	----	n	n
56	----	----	n	n
57	----	----	n	n
58	----	----	n	n
59	----	----	n	n
60	----	----	n	n
61	----	----	n	n
62	----	----	n	n
63	----	----	n	n
64	----	----	n	n
65	----	----	n	n
66	----	----	n	n
67	----	----	n	n
68	----	----	n	n
69	----	----	n	n
70	----	----	n	n
71	----	----	n	n
72	----	----	n	n
73	----	----	n	n
74	----	----	n	n
75	----	----	n	n
76	----	----	n	n
77	----	----	n	n
78	----	----	n	n
79	----	----	n	n
80	----	----	n	n
81	----	----	n	n
82	----	----	n	n
83	----	----	n	n
84	----	----	n	n
85	----	----	n	n
86	----	----	n	n
87	----	----	n	n
88	----	----	n	n
89	----	----	n	n
90	----	----	n	n
91	----	----	n	n
92	----	----	n	n
93	----	----	n	n
94	----	----	n	n
95	----	----	n	n
96	----	----	n	n
97	----	----	n	n
98	----	----	n	n
99	----	----	n	n
100	----	----	n	n

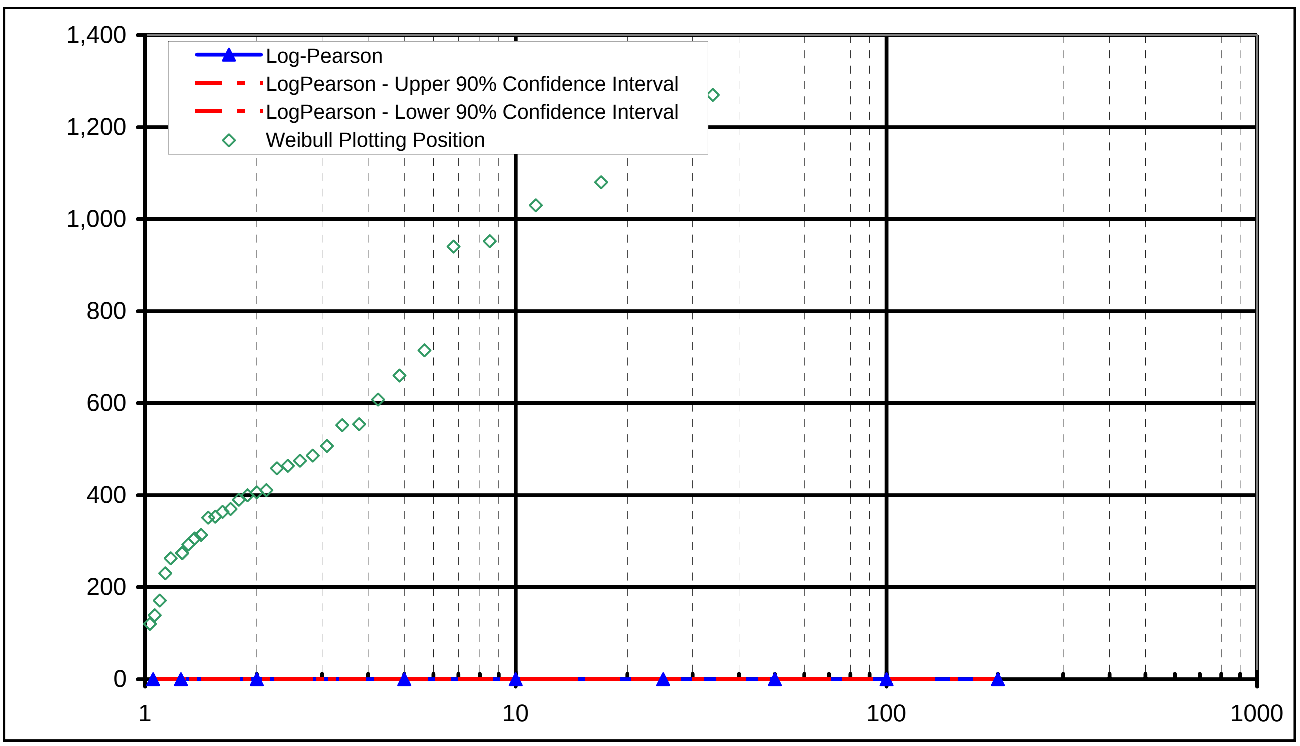
	Date	Discharge (cfs)	Historic?	Outlier?
101	----	----	n	n
102	----	----	n	n
103	----	----	n	n
104	----	----	n	n
105	----	----	n	n
106	----	----	n	n
107	----	----	n	n
108	----	----	n	n
109	----	----	n	n
110	----	----	n	n
111	----	----	n	n
112	----	----	n	n
113	----	----	n	n
114	----	----	n	n
115	----	----	n	n
116	----	----	n	n
117	----	----	n	n
118	----	----	n	n
119	----	----	n	n
120	----	----	n	n
121	----	----	n	n
122	----	----	n	n
123	----	----	n	n
124	----	----	n	n
125	----	----	n	n
126	----	----	n	n
127	----	----	n	n
128	----	----	n	n
129	----	----	n	n
130	----	----	n	n
131	----	----	n	n
132	----	----	n	n
133	----	----	n	n
134	----	----	n	n
135	----	----	n	n
136	----	----	n	n
137	----	----	n	n
138	----	----	n	n
139	----	----	n	n
140	----	----	n	n
141	----	----	n	n
142	----	----	n	n
143	----	----	n	n
144	----	----	n	n
145	----	----	n	n
146	----	----	n	n
147	----	----	n	n
148	----	----	n	n
149	----	----	n	n
150	----	----	n	n

Project: *Dullknife Dam Breach Analysis*
Streamgage: *# USGS 06311500 NORTH FORK POWDER RIVER NEAR MAYOWORTH, WY*
Date: *11/19/2004* **Performed By:** *Steve Yochum*

Discharge-Frequency, with Gage Skew
 # USGS 06311500 NORTH FORK POWDER RIVER NEAR MAYOWORTH, WY



Discharge-Frequency, with Generalized Skew
 # USGS 06311500 NORTH FORK POWDER RIVER NEAR MAYOWORTH, WY



NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *Dullknife Dam Breach Analysis*
Streamgage: # *USGS 06311400 NF POWDER RIVER BELOW PASS CREEK, NR MAYOWORTH, WY*
Date: *11/19/2004* **Performed By:** *Steve Yochum*

Without Generalized Skew

Average: 5.6806
Standard Deviation: 0.79104802
Skew Coefficient(1)**:** 0.75832216

Length of systematic record: 25
Number of historic peaks: 0
Length of Data Record: 25
Length of Historic Record:(5) ----

With Generalized Skew

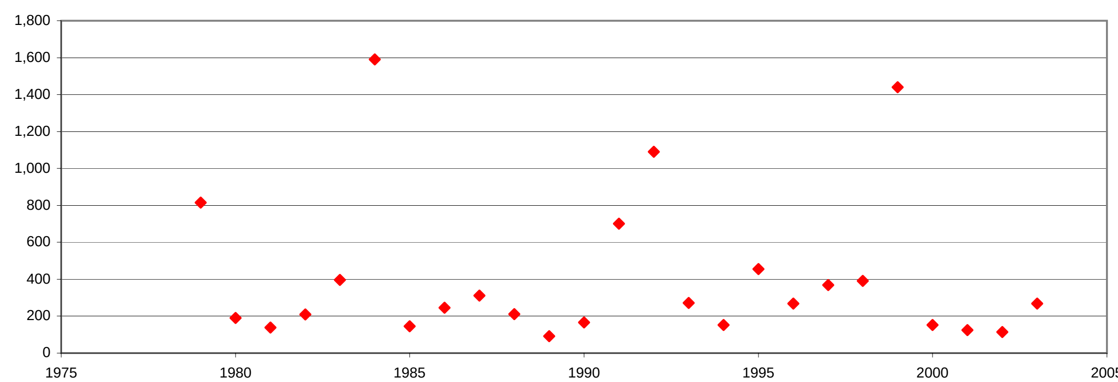
Generalized Skew Coefficient(3)**:**
Variance of Generalized Skew(3)**:**
A: -0.269334
B: 0.742836
station skew: 0.758322
MSE Station Skew: 0.2723087
Weighted skew coefficient(1)**:** 0

Recurrence Interval(2) (years)	Percent Chance	K-Value	Ln(Q)	Peak(4) Discharge (cfs)	90% Confidence Interval Upper (cfs)	90% Confidence Interval Lower (cfs)
Without Generalized Skew						
200	0.5	3.275	8.2712	3,910	9,230	2,260
100	1	2.863	7.9454	2,820	6,070	1,720
50	2	2.434	7.6059	2,010	3,920	1,300
25	4	1.982	7.2486	1,410	2,490	959
10	10	1.335	6.7365	843	1,310	615
5	20	0.784	6.3009	545	771	415
2	50	-0.125	5.5815	265	345	202
1.25	80	-0.856	5.0031	149	196	104
1.05	95	-1.403	4.5711	97	133	61
With Generalized Skew						
200	0.5	2.576	7.7183	----	----	----
100	1	2.326	7.5206	----	----	----
50	2	2.054	7.3054	----	----	----
25	4	1.751	7.0657	----	----	----
10	10	1.282	6.6947	----	----	----
5	20	0.842	6.3467	----	----	----
2	50	0.000	5.6806	----	----	----
1.25	80	-0.842	5.0145	----	----	----
1.05	95	-1.645	4.3793	----	----	----

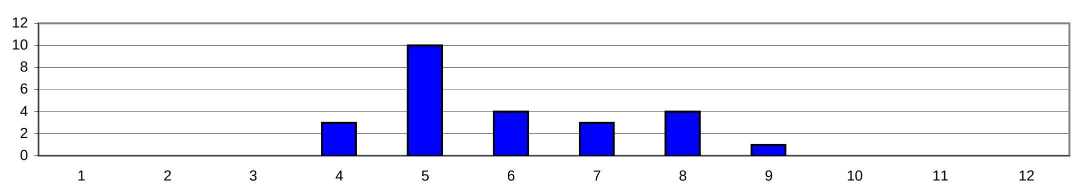
(1) Station and generalized skews must be between -2.00 and +3.00 in this spreadsheet.
(2) Considering the relatively short length of most gage records, less frequent peak estimates need to be used with considerable care.
(3) Computed one of four ways (see "generalized skew coefficient" worksheet): Mean and variance (standard deviation ^{2}) of station skews coefficients in region; skew isolines drawn on a map or regions; skew prediction equations; read from Plate 1 of Bulletin 17B (reproduced in this spreadsheet), with MSE Generalized Skew = 0.302.
(4) Results are automatically rounded to three significant figures, the dominant number of significant figures in the K-Value table.
(5) Historic frequency analysis assumes that intervening years reflect systematic record.

Comments:

Data Plot:



Peak Timing:



NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *Dullknife Dam Breach Analysis*
Streamgage: *# USGS 06311400 NF POWDER RIVER BELOW PASS CREEK, NR MAYOWORTH, WY*
Date: *11/19/2004* **Performed By:** *Steve Yochum*

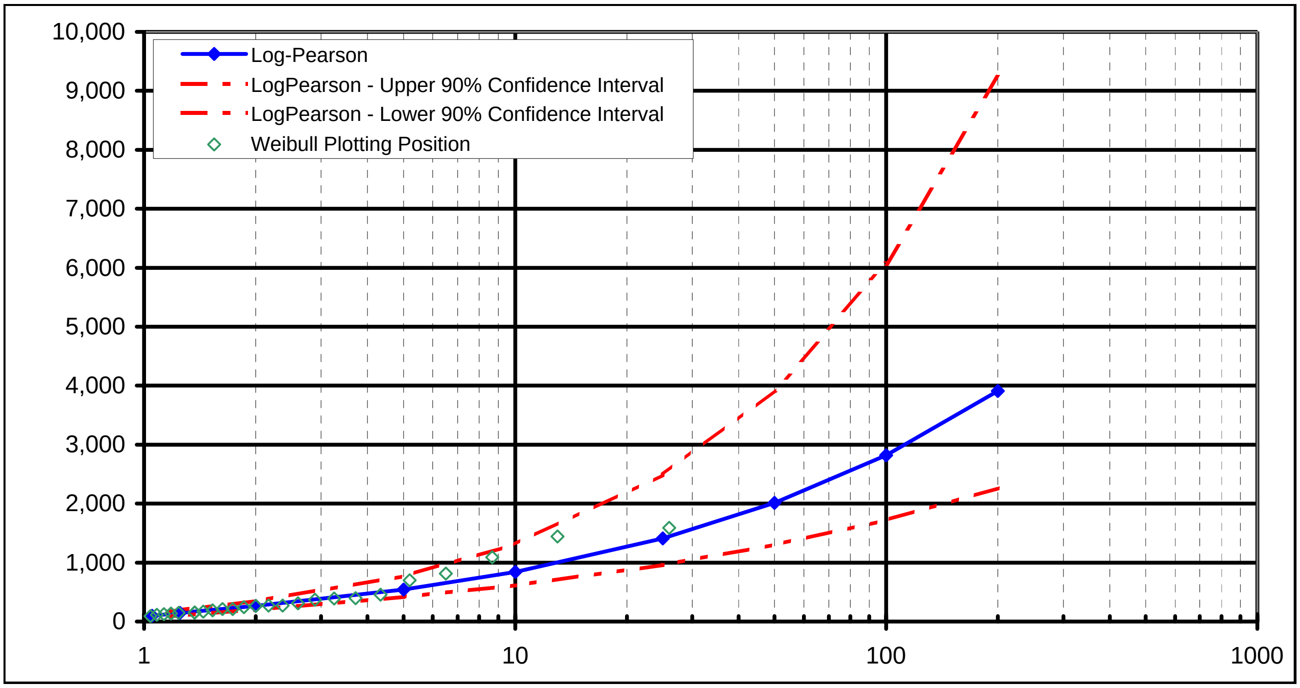
Input Data

Station ID: *06311400* **Latitude, Longitude:** *43,54,41* *106,53,20*
Drainage Area (mi^2): *100* **County:** *Johnson*
Number of low outliers eliminated: *0* **State:** *WY*

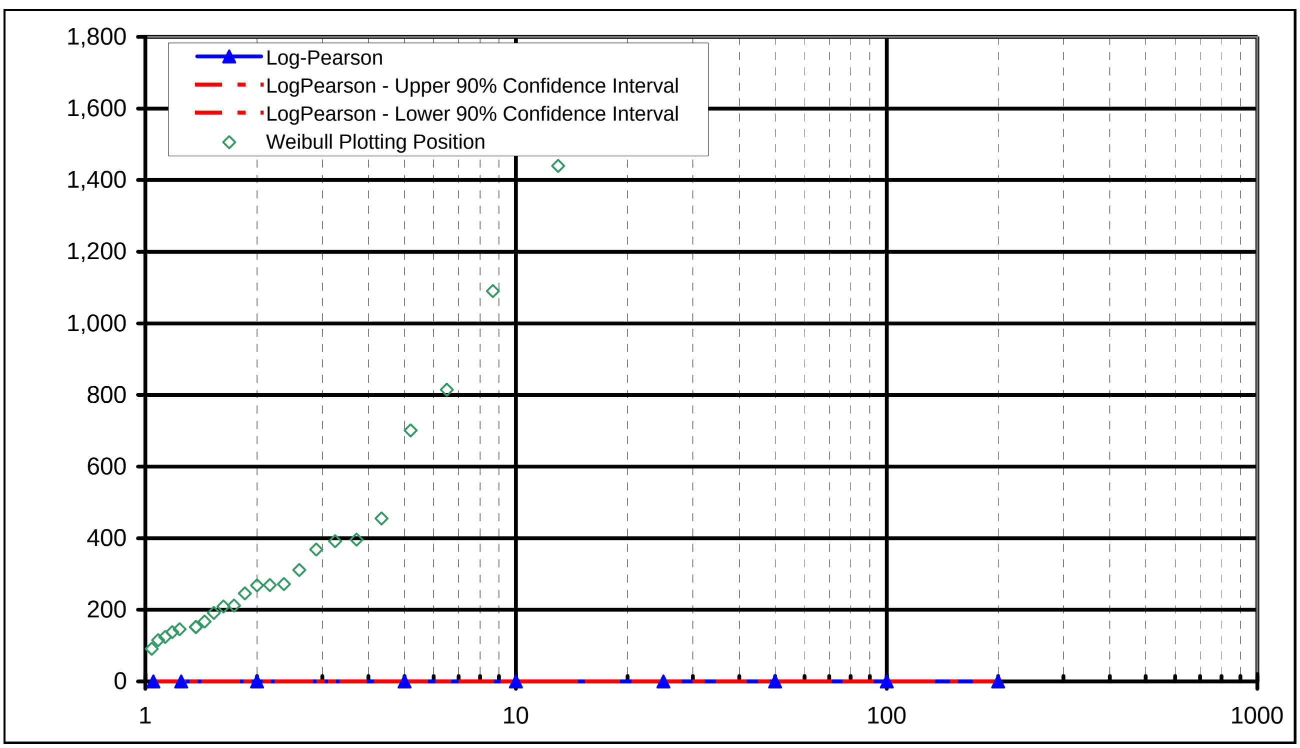
	Date	Discharge (cfs)	Historic?	Outlier?		Date	Discharge (cfs)	Historic?	Outlier?		Date	Discharge (cfs)	Historic?	Outlier?
1	08/18/1979	815	n	n	51	----	----	n	n	101	----	----	n	n
2	04/22/1980	191	n	n	52	----	----	n	n	102	----	----	n	n
3	05/27/1981	138	n	n	53	----	----	n	n	103	----	----	n	n
4	06/17/1982	209	n	n	54	----	----	n	n	104	----	----	n	n
5	05/28/1983	396	n	n	55	----	----	n	n	105	----	----	n	n
6	08/01/1984	1,590	n	n	56	----	----	n	n	106	----	----	n	n
7	05/04/1985	146	n	n	57	----	----	n	n	107	----	----	n	n
8	07/26/1986	246	n	n	58	----	----	n	n	108	----	----	n	n
9	04/17/1987	311	n	n	59	----	----	n	n	109	----	----	n	n
10	05/14/1988	212	n	n	60	----	----	n	n	110	----	----	n	n
11	05/19/1989	91	n	n	61	----	----	n	n	111	----	----	n	n
12	05/25/1990	167	n	n	62	----	----	n	n	112	----	----	n	n
13	09/10/1991	701	n	n	63	----	----	n	n	113	----	----	n	n
14	06/15/1992	1,090	n	n	64	----	----	n	n	114	----	----	n	n
15	05/28/1993	272	n	n	65	----	----	n	n	115	----	----	n	n
16	05/13/1994	152	n	n	66	----	----	n	n	116	----	----	n	n
17	06/06/1995	455	n	n	67	----	----	n	n	117	----	----	n	n
18	05/14/1996	269	n	n	68	----	----	n	n	118	----	----	n	n
19	06/08/1997	368	n	n	69	----	----	n	n	119	----	----	n	n
20	08/03/1998	392	n	n	70	----	----	n	n	120	----	----	n	n
21	08/03/1999	1,440	n	n	71	----	----	n	n	121	----	----	n	n
22	05/17/2000	152	n	n	72	----	----	n	n	122	----	----	n	n
23	07/10/2001	124	n	n	73	----	----	n	n	123	----	----	n	n
24	07/21/2002	115	n	n	74	----	----	n	n	124	----	----	n	n
25	04/14/2003	268	n	n	75	----	----	n	n	125	----	----	n	n
26	----	----	n	n	76	----	----	n	n	126	----	----	n	n
27	----	----	n	n	77	----	----	n	n	127	----	----	n	n
28	----	----	n	n	78	----	----	n	n	128	----	----	n	n
29	----	----	n	n	79	----	----	n	n	129	----	----	n	n
30	----	----	n	n	80	----	----	n	n	130	----	----	n	n
31	----	----	n	n	81	----	----	n	n	131	----	----	n	n
32	----	----	n	n	82	----	----	n	n	132	----	----	n	n
33	----	----	n	n	83	----	----	n	n	133	----	----	n	n
34	----	----	n	n	84	----	----	n	n	134	----	----	n	n
35	----	----	n	n	85	----	----	n	n	135	----	----	n	n
36	----	----	n	n	86	----	----	n	n	136	----	----	n	n
37	----	----	n	n	87	----	----	n	n	137	----	----	n	n
38	----	----	n	n	88	----	----	n	n	138	----	----	n	n
39	----	----	n	n	89	----	----	n	n	139	----	----	n	n
40	----	----	n	n	90	----	----	n	n	140	----	----	n	n
41	----	----	n	n	91	----	----	n	n	141	----	----	n	n
42	----	----	n	n	92	----	----	n	n	142	----	----	n	n
43	----	----	n	n	93	----	----	n	n	143	----	----	n	n
44	----	----	n	n	94	----	----	n	n	144	----	----	n	n
45	----	----	n	n	95	----	----	n	n	145	----	----	n	n
46	----	----	n	n	96	----	----	n	n	146	----	----	n	n
47	----	----	n	n	97	----	----	n	n	147	----	----	n	n
48	----	----	n	n	98	----	----	n	n	148	----	----	n	n
49	----	----	n	n	99	----	----	n	n	149	----	----	n	n
50	----	----	n	n	100	----	----	n	n	150	----	----	n	n

Project: *Dullknife Dam Breach Analysis*
Streamgage: *# USGS 06311400 NF POWDER RIVER BELOW PASS CREEK, NR MAYOWORTH, WY*
Date: *11/19/2004* **Performed By:** *Steve Yochum*

Discharge-Frequency, with Gage Skew
 # USGS 06311400 NF POWDER RIVER BELOW PASS CREEK, NR MAYOWORTH, WY



Discharge-Frequency, with Generalized Skew
 # USGS 06311400 NF POWDER RIVER BELOW PASS CREEK, NR MAYOWORTH, WY



NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *Dullknife Dam Breach Analysis*
Streamgage: *# USGS 06312500 POWDER RIVER NEAR KAYCEE, WYO.*
Date: *11/22/2004* **Performed By:** *Steve Yochum*

Without Generalized Skew

Average:	7.2451
Standard Deviation:	0.61916734
Skew Coefficient[(1)]:	0.09914463
Length of systematic record:	39
Number of historic peaks:	0
Length of Data Record:	39
Length of Historic Record:[(5)]	----

With Generalized Skew

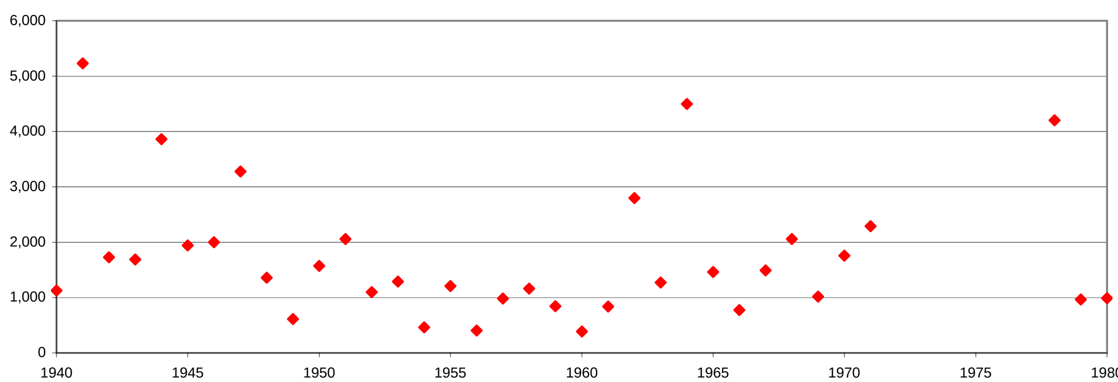
Generalized Skew Coefficient[(3)]:	0.0000
Variance of Generalized Skew[(3)]:	0.3020
A:	-0.322068
B:	0.914222
station skew:	0.099145
MSE Station Skew:	0.13726729
Weighted skew coefficient[(1)]:	0.06816277

Recurrence Interval[(2)] (years)	Percent Chance	K-Value	Ln(Q)	Peak[(4)] Discharge (cfs)	90% Confidence Interval Upper (cfs)	Lower (cfs)
200	0.5	2.669	8.8978	7,320	11,200	5,410
100	1	2.399	8.7307	6,190	9,140	4,680
50	2	2.107	8.5494	5,160	7,350	4,000
25	4	1.785	8.3501	4,230	5,790	3,360
10	10	1.292	8.0450	3,120	4,030	2,560
5	20	0.836	7.7628	2,350	2,910	1,970
2	50	-0.017	7.2347	1,390	1,640	1,170
1.25	80	-0.846	6.7213	830	989	670
1.05	95	-1.616	6.2444	515	642	384
200	0.5	2.640	8.8798	7,190	10,900	5,320
100	1	2.376	8.7165	6,100	8,980	4,620
50	2	2.090	8.5392	5,110	7,260	3,960
25	4	1.774	8.3436	4,200	5,740	3,340
10	10	1.289	8.0431	3,110	4,030	2,550
5	20	0.838	7.7639	2,350	2,920	1,980
2	50	-0.012	7.2379	1,390	1,640	1,180
1.25	80	-0.845	6.7221	831	990	670
1.05	95	-1.625	6.2388	512	639	382

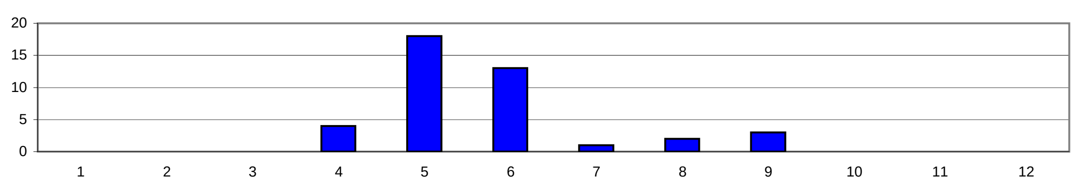
(1) Station and generalized skews must be between -2.00 and +3.00 in this spreadsheet.
(2) Considering the relatively short length of most gage records, less frequent peak estimates need to be used with considerable care.
(3) Computed one of four ways (see "generalized skew coefficient" worksheet): Mean and variance (standard deviation ^{2}) of station skews coefficients in region; skew isolines drawn on a map or regions; skew prediction equations; read from Plate 1 of Bulletin 17B (reproduced in this spreadsheet), with MSE Generalized Skew = 0.302.
(4) Results are automatically rounded to three significant figures, the dominant number of significant figures in the K-Value table.
(5) Historic frequency analysis assumes that intervening years reflect systematic record.

Comments:

Data Plot:



Peak Timing:



NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *Dullknife Dam Breach Analysis*
Streamgage: *# USGS 06312500 POWDER RIVER NEAR KAYCEE, WYO.*
Date: *11/22/2004* **Performed By:** *Steve Yochum*

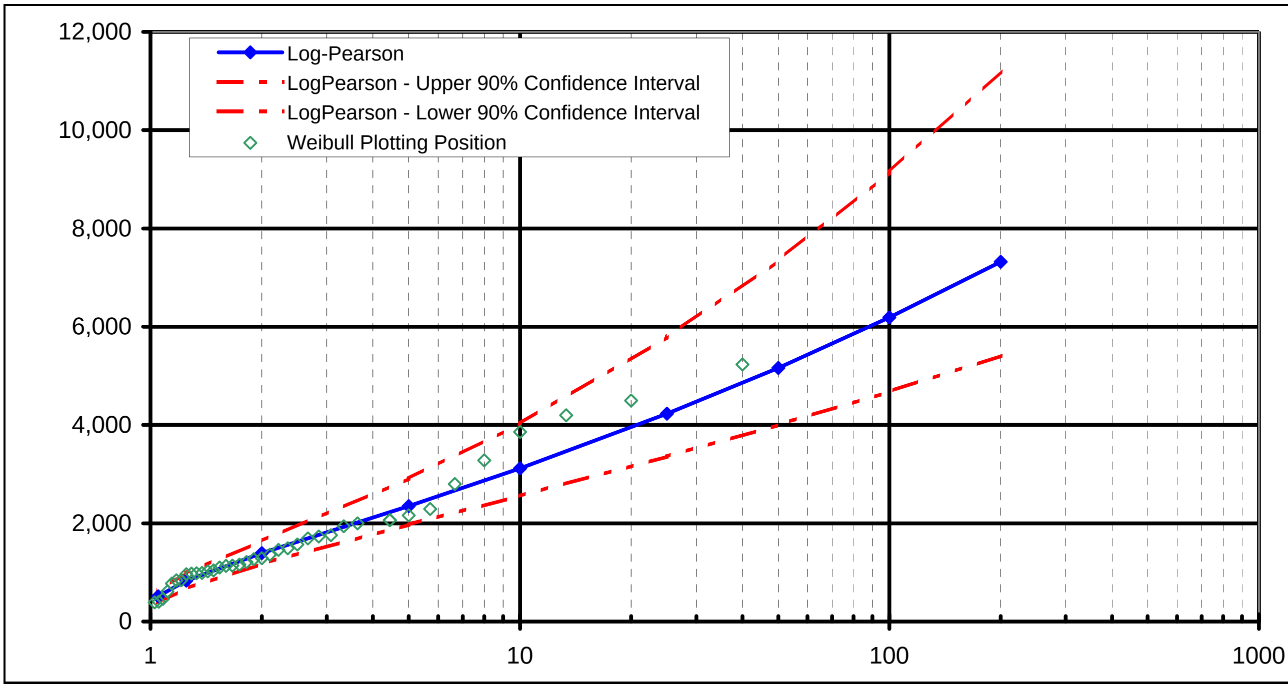
Input Data

Station ID: *06312500* **Latitude, Longitude:** -- --
Drainage Area (mi^2): *980* **County:** *Johnson*
Number of low outliers eliminated: *0* **State:** *WY*

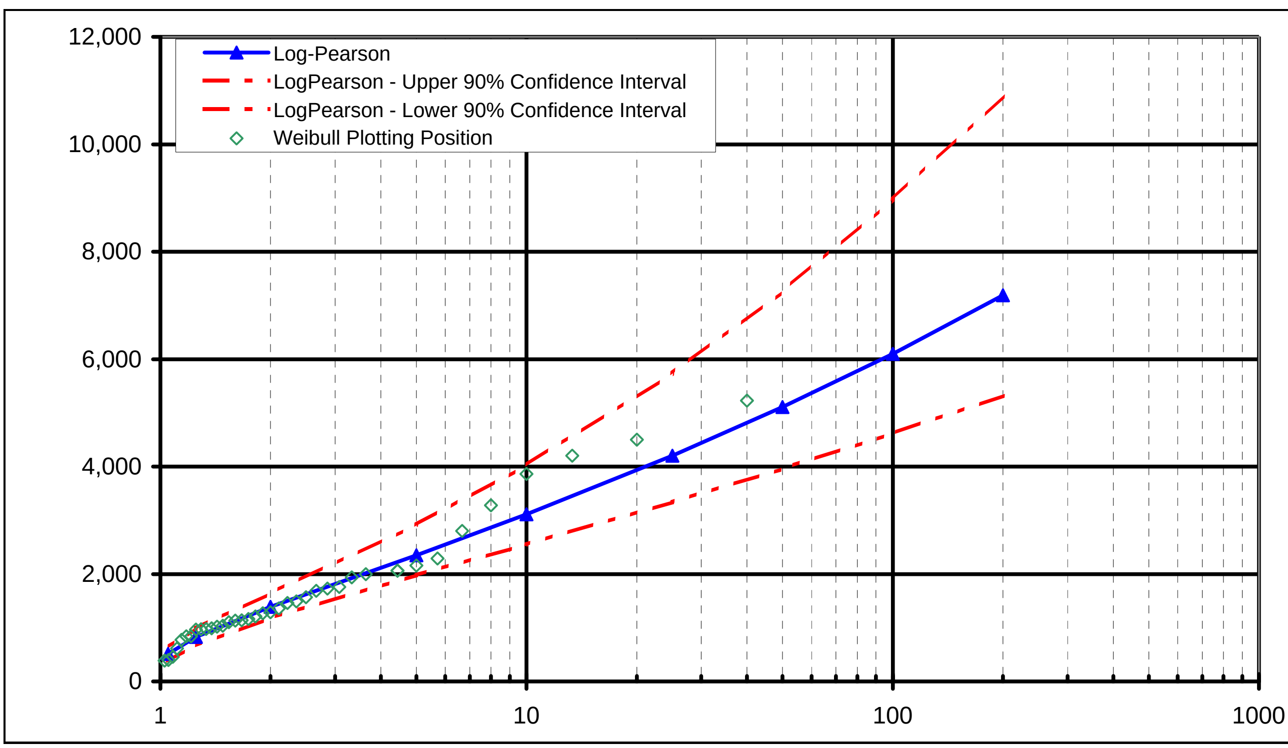
	Date	Discharge (cfs)	Historic?	Outlier?		Date	Discharge (cfs)	Historic?	Outlier?		Date	Discharge (cfs)	Historic?	Outlier?
1	09/30/1923	----	n	n	51	----	----	n	n	101	----	----	n	n
2	06/06/1934	2,160	n	n	52	----	----	n	n	102	----	----	n	n
3	05/31/1935	1,040	n	n	53	----	----	n	n	103	----	----	n	n
4	06/01/1936	----	n	n	54	----	----	n	n	104	----	----	n	n
5	05/01/1938	1,140	n	n	55	----	----	n	n	105	----	----	n	n
6	06/01/1939	974	n	n	56	----	----	n	n	106	----	----	n	n
7	09/30/1940	1,130	n	n	57	----	----	n	n	107	----	----	n	n
8	08/11/1941	5,230	n	n	58	----	----	n	n	108	----	----	n	n
9	04/15/1942	1,730	n	n	59	----	----	n	n	109	----	----	n	n
10	06/12/1943	1,690	n	n	60	----	----	n	n	110	----	----	n	n
11	05/19/1944	3,860	n	n	61	----	----	n	n	111	----	----	n	n
12	06/11/1945	1,940	n	n	62	----	----	n	n	112	----	----	n	n
13	07/02/1946	2,000	n	n	63	----	----	n	n	113	----	----	n	n
14	05/06/1947	3,280	n	n	64	----	----	n	n	114	----	----	n	n
15	05/21/1948	1,360	n	n	65	----	----	n	n	115	----	----	n	n
16	04/30/1949	614	n	n	66	----	----	n	n	116	----	----	n	n
17	05/18/1950	1,570	n	n	67	----	----	n	n	117	----	----	n	n
18	09/07/1951	2,060	n	n	68	----	----	n	n	118	----	----	n	n
19	05/22/1952	1,100	n	n	69	----	----	n	n	119	----	----	n	n
20	06/06/1953	1,290	n	n	70	----	----	n	n	120	----	----	n	n
21	05/11/1954	461	n	n	71	----	----	n	n	121	----	----	n	n
22	05/15/1955	1,210	n	n	72	----	----	n	n	122	----	----	n	n
23	05/10/1956	402	n	n	73	----	----	n	n	123	----	----	n	n
24	06/21/1957	980	n	n	74	----	----	n	n	124	----	----	n	n
25	05/13/1958	1,160	n	n	75	----	----	n	n	125	----	----	n	n
26	05/17/1959	842	n	n	76	----	----	n	n	126	----	----	n	n
27	04/24/1960	389	n	n	77	----	----	n	n	127	----	----	n	n
28	05/25/1961	839	n	n	78	----	----	n	n	128	----	----	n	n
29	06/01/1962	2,800	n	n	79	----	----	n	n	129	----	----	n	n
30	06/15/1963	1,270	n	n	80	----	----	n	n	130	----	----	n	n
31	06/22/1964	4,500	n	n	81	----	----	n	n	131	----	----	n	n
32	06/15/1965	1,460	n	n	82	----	----	n	n	132	----	----	n	n
33	05/08/1966	772	n	n	83	----	----	n	n	133	----	----	n	n
34	06/15/1967	1,490	n	n	84	----	----	n	n	134	----	----	n	n
35	06/09/1968	2,060	n	n	85	----	----	n	n	135	----	----	n	n
36	04/24/1969	1,020	n	n	86	----	----	n	n	136	----	----	n	n
37	05/25/1970	1,760	n	n	87	----	----	n	n	137	----	----	n	n
38	05/30/1971	2,290	n	n	88	----	----	n	n	138	----	----	n	n
39	05/01/1978	4,200	n	n	89	----	----	n	n	139	----	----	n	n
40	05/17/1979	965	n	n	90	----	----	n	n	140	----	----	n	n
41	08/15/1980	987	n	n	91	----	----	n	n	141	----	----	n	n
42	----	----	n	n	92	----	----	n	n	142	----	----	n	n
43	----	----	n	n	93	----	----	n	n	143	----	----	n	n
44	----	----	n	n	94	----	----	n	n	144	----	----	n	n
45	----	----	n	n	95	----	----	n	n	145	----	----	n	n
46	----	----	n	n	96	----	----	n	n	146	----	----	n	n
47	----	----	n	n	97	----	----	n	n	147	----	----	n	n
48	----	----	n	n	98	----	----	n	n	148	----	----	n	n
49	----	----	n	n	99	----	----	n	n	149	----	----	n	n
50	----	----	n	n	100	----	----	n	n	150	----	----	n	n

Project: *Dullknife Dam Breach Analysis*
Streamgage: *# USGS 06312500 POWDER RIVER NEAR KAYCEE, WYO.*
Date: *11/22/2004* **Performed By:** *Steve Yochum*

Discharge-Frequency, with Gage Skew
 # USGS 06312500 POWDER RIVER NEAR KAYCEE, WYO.



Discharge-Frequency, with Generalized Skew
 # USGS 06312500 POWDER RIVER NEAR KAYCEE, WYO.



NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *Dullknife Dam Breach Analysis*
Streamgage: *POWDER RIVER AT SUSSEX, WY*
Date: *12/14/2004* **Performed By:** *Steve Yochum*

Without Generalized Skew

Average:	8.2450
Standard Deviation:	0.89674723
Skew Coefficient[1]:	0.65597185
Length of systematic record:	32
Number of historic peaks:	0
Length of Data Record:	32
Length of Historic Record:[5]	----

With Generalized Skew

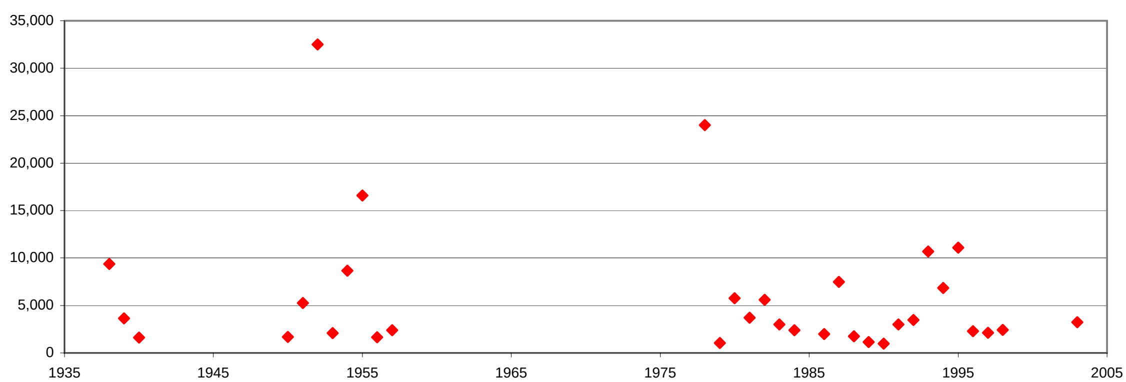
Generalized Skew Coefficient[3]:	0.0000
Variance of Generalized Skew[3]:	0.3020
A:	-0.277522
B:	0.769447
station skew:	0.655972
MSE Station Skew:	0.21567085
Weighted skew coefficient[1]:	0.38268235

Recurrence Interval[2] (years)	Percent Chance	K-Value	Ln(Q)	Peak[4] Discharge (cfs)	90% Confidence Interval Upper (cfs)	90% Confidence Interval Lower (cfs)
200	0.5	3.183	11.0993	66,100	148,000	38,200
100	1	2.794	10.7502	46,600	96,100	28,400
50	2	2.386	10.3845	32,400	61,100	20,800
25	4	1.955	9.9978	22,000	38,000	14,900
10	10	1.331	9.4384	12,600	19,300	9,140
5	20	0.794	8.9574	7,760	10,900	5,890
2	50	-0.109	8.1477	3,460	4,490	2,630
1.25	80	-0.857	7.4765	1,770	2,340	1,240
1.05	95	-1.438	6.9551	1,050	1,460	671
200	0.5	2.933	10.8751	52,800	112,000	31,600
100	1	2.603	10.5790	39,300	77,700	24,600
50	2	2.252	10.2648	28,700	52,700	18,800
25	4	1.875	9.9261	20,500	34,800	14,000
10	10	1.316	9.4248	12,400	18,900	9,030
5	20	0.817	8.9780	7,930	11,200	6,010
2	50	-0.063	8.1883	3,600	4,690	2,750
1.25	80	-0.855	7.4786	1,770	2,340	1,250
1.05	95	-1.529	6.8735	966	1,360	608

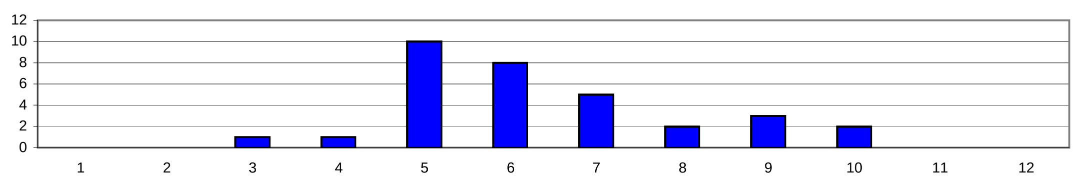
(1) Station and generalized skews must be between -2.00 and +3.00 in this spreadsheet.
(2) Considering the relatively short length of most gage records, less frequent peak estimates need to be used with considerable care.
(3) Computed one of four ways (see "generalized skew coefficient" worksheet): Mean and variance (standard deviation ^{2}) of station skews coefficients in region; skew isolines drawn on a map or regions; skew prediction equations; read from Plate 1 of Bulletin 17B (reproduced in this spreadsheet), with MSE Generalized Skew = 0.302.
(4) Results are automatically rounded to three significant figures, the dominant number of significant figures in the K-Value table.
(5) Historic frequency analysis assumes that intervening years reflect systematic record.

Comments:

Data Plot:



Peak Timing:



NRCS Log-Pearson Frequency Analysis Spreadsheet, Version 2.1beta, 5/2003

Project: *Dullknife Dam Breach Analysis*
Streamgage: *POWDER RIVER AT SUSSEX, WY*
Date: *12/14/2004* **Performed By:** *Steve Yochum*

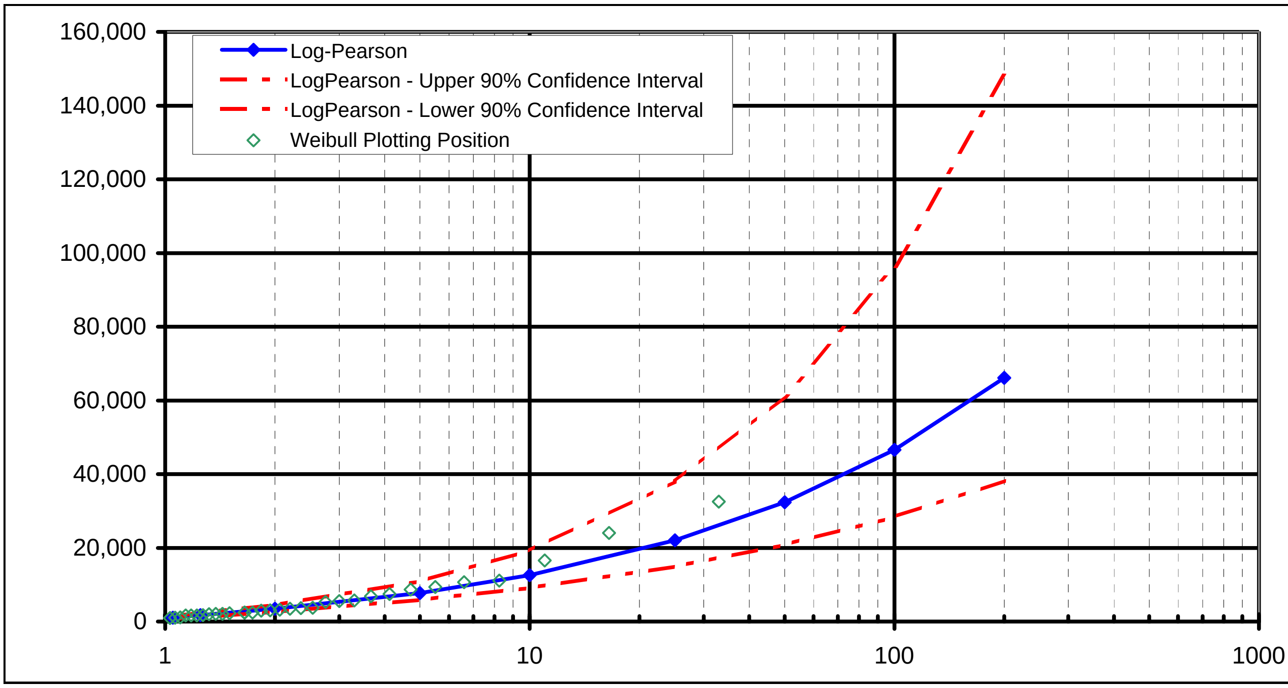
Input Data

Station ID: *06313500* **Latitude, Longitude:** *43,41,44* *106,18,24*
Drainage Area (mi^2): *3090* **County:** *Johnson*
Number of low outliers eliminated: *0* **State:** *WY*

	Date	Discharge (cfs)	Historic?	Outlier?		Date	Discharge (cfs)	Historic?	Outlier?		Date	Discharge (cfs)	Historic?	Outlier?
1	07/26/1938	9,390	n	n	51	----	----	n	n	101	----	----	n	n
2	06/01/1939	3,630	n	n	52	----	----	n	n	102	----	----	n	n
3	04/19/1940	1,610	n	n	53	----	----	n	n	103	----	----	n	n
4	05/18/1950	1,680	n	n	54	----	----	n	n	104	----	----	n	n
5	09/07/1951	5,270	n	n	55	----	----	n	n	105	----	----	n	n
6	05/23/1952	32,500	n	n	56	----	----	n	n	106	----	----	n	n
7	08/03/1953	2,080	n	n	57	----	----	n	n	107	----	----	n	n
8	07/17/1954	8,680	n	n	58	----	----	n	n	108	----	----	n	n
9	06/17/1955	16,600	n	n	59	----	----	n	n	109	----	----	n	n
10	05/28/1956	1,660	n	n	60	----	----	n	n	110	----	----	n	n
11	06/11/1957	2,400	n	n	61	----	----	n	n	111	----	----	n	n
12	05/19/1978	24,000	n	n	62	----	----	n	n	112	----	----	n	n
13	05/17/1979	1,040	n	n	63	----	----	n	n	113	----	----	n	n
14	05/28/1980	5,760	n	n	64	----	----	n	n	114	----	----	n	n
15	07/27/1981	3,720	n	n	65	----	----	n	n	115	----	----	n	n
16	06/24/1982	5,590	n	n	66	----	----	n	n	116	----	----	n	n
17	08/05/1983	2,990	n	n	67	----	----	n	n	117	----	----	n	n
18	03/15/1984	2,400	n	n	68	----	----	n	n	118	----	----	n	n
19	09/11/1986	2,000	n	n	69	----	----	n	n	119	----	----	n	n
20	10/23/1986	7,480	n	n	70	----	----	n	n	120	----	----	n	n
21	06/14/1988	1,770	n	n	71	----	----	n	n	121	----	----	n	n
22	06/09/1989	1,140	n	n	72	----	----	n	n	122	----	----	n	n
23	05/30/1990	975	n	n	73	----	----	n	n	123	----	----	n	n
24	05/16/1991	3,000	n	n	74	----	----	n	n	124	----	----	n	n
25	07/02/1992	3,470	n	n	75	----	----	n	n	125	----	----	n	n
26	05/06/1993	10,700	n	n	76	----	----	n	n	126	----	----	n	n
27	07/07/1994	6,830	n	n	77	----	----	n	n	127	----	----	n	n
28	10/17/1994	11,100	n	n	78	----	----	n	n	128	----	----	n	n
29	05/25/1996	2,290	n	n	79	----	----	n	n	129	----	----	n	n
30	06/13/1997	2,120	n	n	80	----	----	n	n	130	----	----	n	n
31	09/13/1998	2,420	n	n	81	----	----	n	n	131	----	----	n	n
32	06/17/2003	3,250	n	n	82	----	----	n	n	132	----	----	n	n
33	----	----	n	n	83	----	----	n	n	133	----	----	n	n
34	----	----	n	n	84	----	----	n	n	134	----	----	n	n
35	----	----	n	n	85	----	----	n	n	135	----	----	n	n
36	----	----	n	n	86	----	----	n	n	136	----	----	n	n
37	----	----	n	n	87	----	----	n	n	137	----	----	n	n
38	----	----	n	n	88	----	----	n	n	138	----	----	n	n
39	----	----	n	n	89	----	----	n	n	139	----	----	n	n
40	----	----	n	n	90	----	----	n	n	140	----	----	n	n
41	----	----	n	n	91	----	----	n	n	141	----	----	n	n
42	----	----	n	n	92	----	----	n	n	142	----	----	n	n
43	----	----	n	n	93	----	----	n	n	143	----	----	n	n
44	----	----	n	n	94	----	----	n	n	144	----	----	n	n
45	----	----	n	n	95	----	----	n	n	145	----	----	n	n
46	----	----	n	n	96	----	----	n	n	146	----	----	n	n
47	----	----	n	n	97	----	----	n	n	147	----	----	n	n
48	----	----	n	n	98	----	----	n	n	148	----	----	n	n
49	----	----	n	n	99	----	----	n	n	149	----	----	n	n
50	----	----	n	n	100	----	----	n	n	150	----	----	n	n

Project: *Dullknife Dam Breach Analysis*
Streamgage: *POWDER RIVER AT SUSSEX, WY*
Date: *12/14/2004* **Performed By:** *Steve Yochum*

Discharge-Frequency, with Gage Skew
POWDER RIVER AT SUSSEX, WY



Discharge-Frequency, with Generalized Skew
POWDER RIVER AT SUSSEX, WY