DOWL ALASKA

# DIXON DIVERSION SEDIMENT MANAGEMENT STUDY

Bradley Lake Expansion Project

**Prepared for:**

ALASKA ENERGY AUTHORITY

**Prepared by:**

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June 2026

# BRADLEY LAKE EXPANSION PROJECT DIXON DIVERSION SEDIMENT MANAGEMENT STUDY

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# EXECUTIVE SUMMARY

The proposed Dixon Diversion Dam, located on the Kenai Peninsula near Homer, Alaska, will divert water from the East Fork Martin River (EFMR) immediately below the Dixon Glacier, through a 4.7-mile-long diversion tunnel to Bradley Lake for hydropower production. The Dixon Diversion Dam will be situated immediately below the toe of the Dixon Glacier with a drainage area of 19.3 mi$^2$. The watershed upstream from the Dixon Diversion is anticipated to provide an average annual water yield of 200,000 ac-ft per year.

Sediment yield from the glaciated watershed could be large and range from 610,000 to 6,100,000 yd$^3$/yr (clay, silt, sand, gravel, and cobble-sized sediment). Assuming that coarse sediment (gravel and cobbles) is 5% of the total loading, the average annual gravel and cobble load ranges from 30,000 to 300,000 yd$^3$/yr. Based on streambed aggradation in the Martin River measured using LiDAR mapping in 2022 and 2024, the annual average coarse sediment yield from the glacier is approximately 40,000 yd$^3$/yr.

The proposed Dixon Diversion consists of several components: the diversion dam, the tunnel intake, the forebay berm, and dike/sediment guide wall (Figure E1). Between the diversion dam and the forebay berm is the diversion pool area (shaded in green), and the area leading from the forebay berm to the tunnel intake is the forebay pool area (shaded blue).

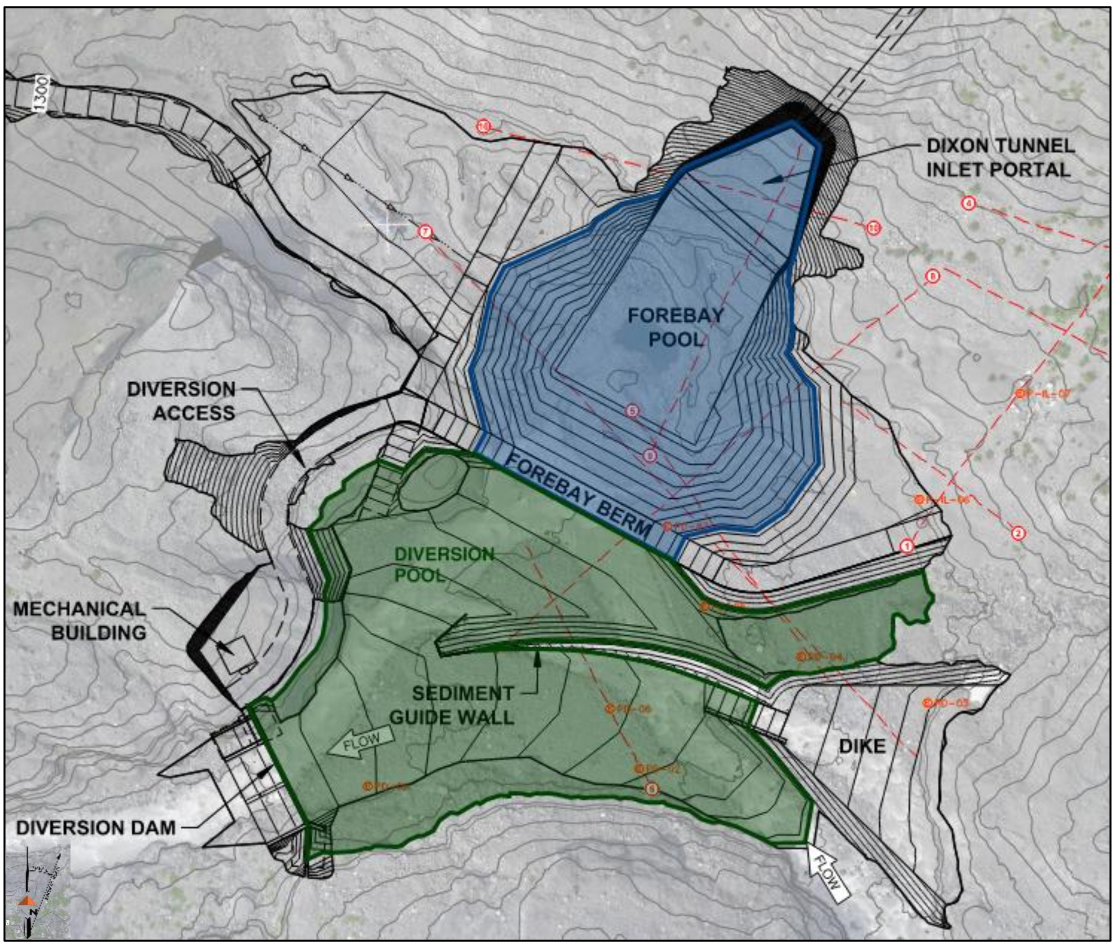



**Figure E1: Dixon Diversion site layout.**

Construction of a sediment guide wall within the diversion pool is planned to steer inflowing sediment particles toward the diversion dam to the Obermeyer gates for flushing when the gates are lowered. The sediment guide wall also creates a longer flow path, giving sediment more settling time, before water is diverted through the tunnel to Bradley Lake.

The diversion pool created by the diversion dam will trap a significant portion of the inflowing sediment load. The portion of the sediment load not trapped will be released downstream to the EFMR or diverted through the diversion tunnel to Bradley Lake. The diversion pool is expected to trap nearly all the inflowing cobbles and gravel-sized particles. Most of the sand-sized particles are expected to deposit, while most of the silt and clay-sized sediment are expected to continue past the diversion pool. Sedimentation will be managed through periodic hydraulic and mechanical flushing of the deposited sediment to the downstream river channel.

A numerical model was developed to simulate sedimentation behind the dam, which also allows for estimating the quantities of sediment that may pass to the downstream channel and through the diversion tunnel. In the absence of sediment load measurements (suspended sediment concentration and bed load), model inputs were estimated as probability distributions for a reasonable range of values. Application of the Monte Carlo approach provided a method for evaluating the uncertainty of the model inputs: average annual bed-material load, the portion of total load that is bed-material load, and the exponent of the sediment-discharge equation.

Based on sediment settling-basin model simulations, there will be significant variability in the annual and daily sediment loads entering the diversion pool. Higher sediment loads will fill the pool more rapidly than lower sediment loads. Once sediment has largely filled the diversion along the front side of the guide wall, hydraulic flushing will be necessary to prevent coarse sediment particles from entering the diversion tunnel. Sedimentation along the back side of the guide wall must be mechanically flushed to maintain the trap efficiency for coarse particles. The sediment flushed to the downstream river channel will primarily consist of cobbles, gravel, and coarse sand.

The annual number of sediment flushes will vary from year to year. The annual number of front side sediment (hydraulic) flushes most likely ranges from 3 to 32 (90% of the years), with a median of 14 flushes per year. The number of back side (mechanical) flushes is similar to the front side, ranging from 2 to 32 (90% of the years), with a median of 13 flushes per year.

# 1.0 INTRODUCTION

The proposed Dixon Diversion Dam will divert water from the East Fork Martin River (EFMR) immediately below the Dixon Glacier, through a 4.7-mile-long diversion tunnel to Bradley Lake for hydropower production. There is no plan for a road to be built; all access will be via helicopter and possibly the diversion tunnel. Given the difficult site access, the diversion will need to be operated remotely. Figure 1 shows the project location on the Kenai Peninsula near Homer, Alaska.

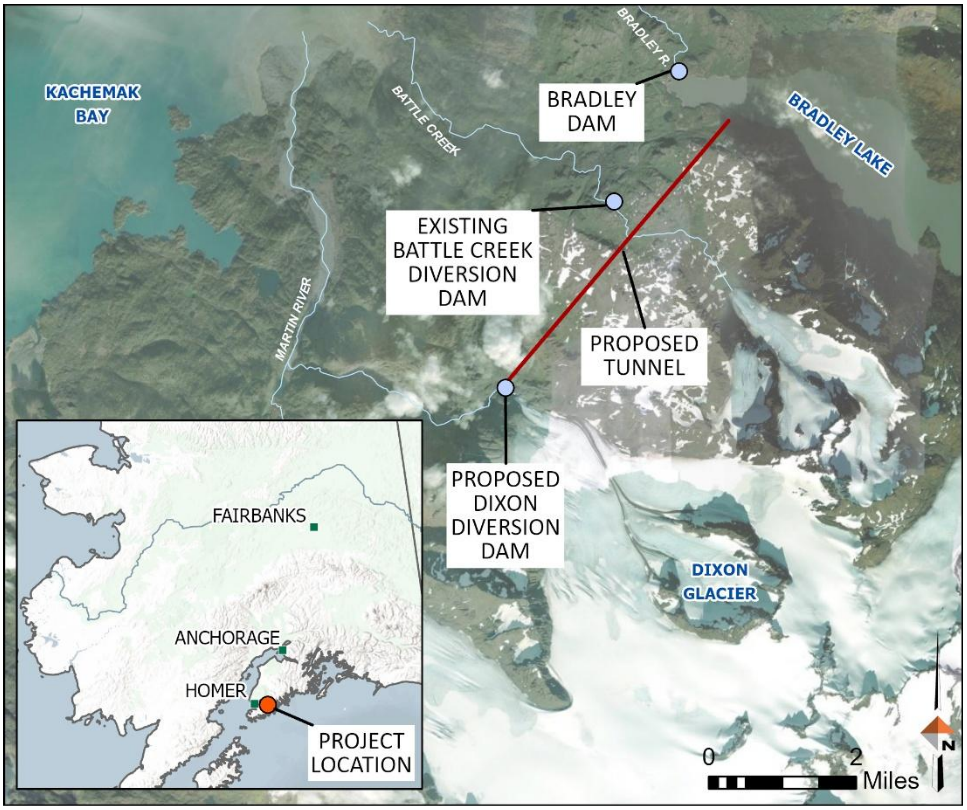



**Figure 1. Project location map.**

The diversion pool created by the diversion dam will trap a portion of the inflowing sediment load. The portion of the sediment load not trapped will be released downstream to the EFMR or diverted through the diversion tunnel to Bradley Lake. The diversion pool is expected to trap nearly all the inflowing cobbles and gravel-sized particles. Most of the sand-sized particles are expected to deposit, while most of the silt and clay-sized sediment are expected to continue past the diversion pool. The sedimentation will be managed through periodic hydraulic and mechanical flushing of the deposited sediment to the downstream river channel. A numerical model was developed to simulate sedimentation, which also allows for estimating the quantities of sediment that may pass to the downstream channel and through the diversion tunnel. The model was also used to predict the frequency of hydraulic and mechanical sediment flushing.

## 1.1 WATERSHED

The Dixon Diversion will be situated immediately below the toe of the Dixon Glacier with a drainage area of 19.3 mi$^2$. Currently, the glacier covers nearly the entire drainage area, but is retreating. Based on Google Earth imagery, the glacier has retreated approximately 2,000 ft upstream along the stream channel since 2003, exposing the Dixon Diversion site.

The watershed upstream from the Dixon Diversion is anticipated to provide an average annual water yield of 200,000 ac-ft per year (based on the past 10 years of record). About half of the water yield is from the 100+ in. of annual precipitation (snow and rain), and the other half is from glacier melting. The *Martin River Hydrology Study Report* provides an estimate of the average annualized glacier-melt volume at 95,000 ac-ft/yr [1].

There are three years of stream gage measurements on the EFMR (2023-2025). Using those three years of record and a gage transform from USGS Station 15238990, the synthetic record on the EFMR extends from 1980 through 2022. The composite hydrograph record on the EFMR is on a daily timestep for 46 years. The *Martin River Hydrology Report* describes the stream gaging program and the basis for the extended hydrograph record (Figure 2 and Figure 3) [1].

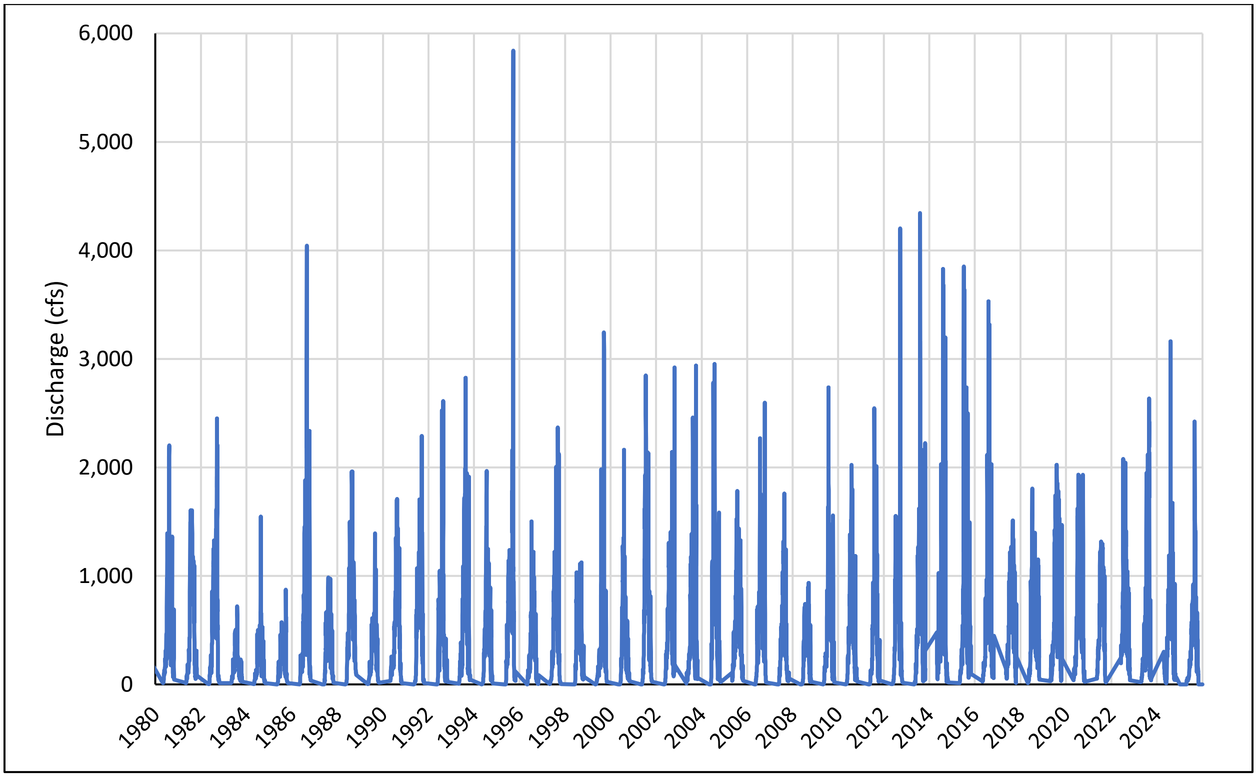



**Figure 2. EFMR hydrograph 1980-2022 (synthetic), 2023-2025 (measured).**

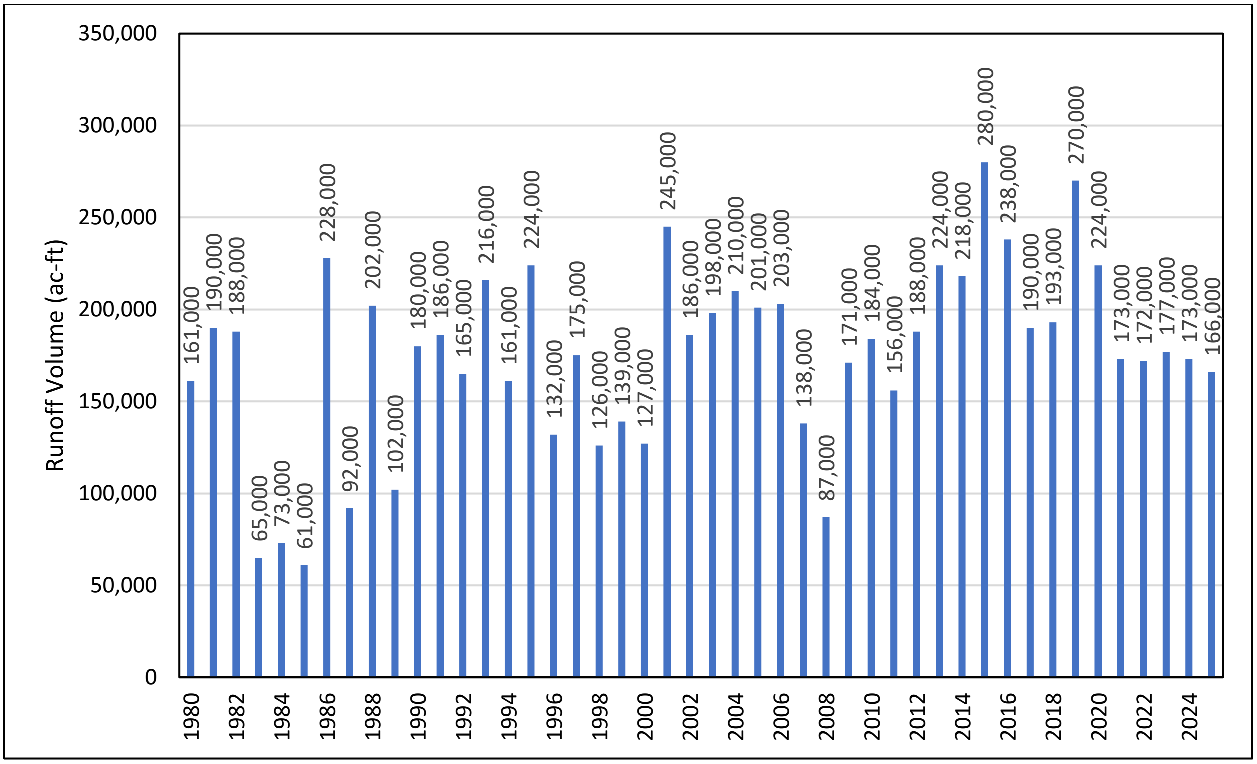



**Figure 3. EFMR runoff volumes 1980-2022 (synthetic), 2023-2025 (measured).**

## 1.2 SEDIMENT SOURCES

Sediment carried to the diversion pool will primarily be released by the Dixon Glacier, which covers most of the drainage area, with additional sediment from the exposed surfaces in the drainage area between the glacier and the diversion dam (Figure 4). Appendix A shows an overview of the drainage area upstream from the Dixon Diversion Dam.

The sediment load rates to the diversion pool have not been measured; therefore, a range of average-annual sediment loads were estimated. First, the range of average-annual bed-material load (gravel and cobble, particles greater than 2 mm) was estimated based on the braid-plain geomorphology of the Martin River downstream [2].

For fast-moving temperate valley glaciers in the tectonically active ranges of southeast Alaska, the glacial erosion rates range from 10 to 100 mm/yr. With a drainage area of 19.3 $mi^2$, the sediment loading may range from 610,000 to 6,100,000 $yd^3$/yr [3]. Assuming that coarse sediment (gravel and cobbles) is 5% of the total loading, the average annual gravel and cobble load ranges from 30,000 to 300,000 $yd^3$/yr. Based on streambed aggradation in the Martin River measured using LiDAR mapping in 2022 and 2024, the annual average coarse sediment yield from the glacier is around 40,000 $yd^3$/yr [4].

The annual gravel and cobble load is only a portion of the annual total sediment load, and the range in gravel and cobble load portion percentages was estimated based on experience in, and data from, other glaciated river systems (Table 1). For example, if the average annual load of gravel and cobble is 40,000 $yd^3$/yr, and that load is 5% of the total load, then the average annual total load is 800,000 $yd^3$/yr. Note these are estimated average annual loads; sediment transport is episodic, and some years will greatly exceed the average, while others will be significantly less than the average.

**Figure 4. Sediment below the toe of the Dixon Glacier (top) and proposed diversion pool (bottom).**

**Table 1. Range of average annual total sediment loads.**

| Annual gravel-cobble sediment yield (yd$^3$/yr) | Gravel-cobble portion of total sediment yield | | | |
|---|---|---|---|---|
| | 3% | 5% | 10% | 15% |
| | Annual total sediment yield (yd$^3$/yr) | | | |
| 10,000 | 333,000 | 200,000 | 100,000 | 66,700 |
| 20,000 | 667,000 | 400,000 | 200,000 | 133,000 |
| 40,000 | 1,333,000 | 800,000 | 400,000 | 267,000 |
| 60,000 | 2,000,000 | 1,200,000 | 600,000 | 400,000 |
| 80,000 | 2,667,000 | 1,600,000 | 800,000 | 533,000 |

As stated above, the daily sediment loads are unknown. However, sediment loads in rivers are typically related to river discharge through an empirical power function, commonly known as a sediment rating curve (Equation *1*):

$$Q_s = a\, Q_w{}^b \qquad (1)$$

Where:
$Q_s$ is the sediment load (or sediment discharge, typically in tons/day),
$Q_w$ is the water discharge (or river discharge),
$a$ is a coefficient related to the sediment availability, and
$b$ is an exponent that defines the power relationship.

The sediment load increases exponentially with discharge, and the exponent ($b$) typically ranges from 1.5 to 3, meaning a small increase in discharge can cause a large increase in sediment transport. If the exponent ($b$) is assumed to be constant (e.g., 1.5, 2.0, 2.5, 3.0), the coefficient ($a$) can be back-calculated so that the summation of computed daily sediment loads over the 46-year period (1980 through 2025) equals an assumed average annual sediment load. For example, if the average annual total sediment load is assumed to be 800,000 yd$^3$/yr, and the exponent ($b$) of Equation 1 is assumed to be 2, then the coefficient ($a$) of Equation 1 can be computed to be $9.1182\times 10^{-3}$.

Applying the following sediment-discharge rating curve equation (Equation 2) to the daily discharge hydrograph produced a daily sediment inflow hydrograph to the diversion pool (Figure 5). In this example, the average sum of the daily sediment loads over the 46-year period equals 800,000 yd$^3$/yr.

$$Q_s = 9.1182 \times 10^{-3}\, Q_w{}^2 \qquad (2)$$

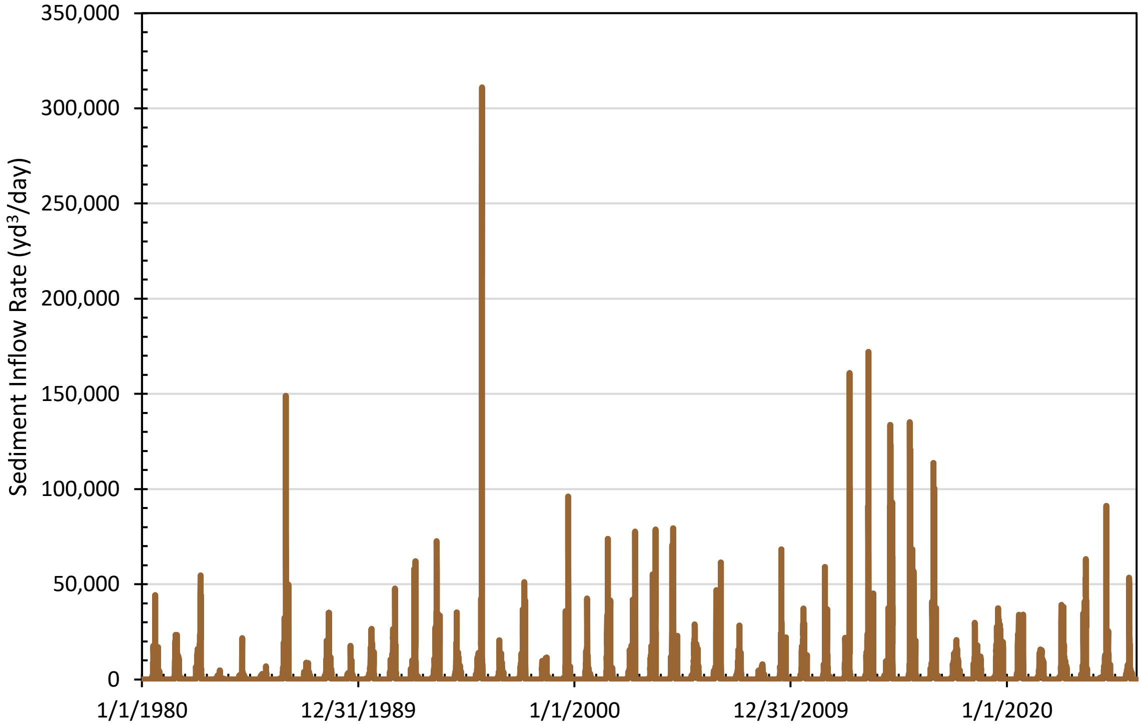



**Figure 5. Example estimates of daily sediment load entering Dixon Diversion for the 46-year period from 1980 through 2025.**

Measured bed material particle size gradations are available for the Martin River (Figure 6). The sediment particles of the bed material surface were transported by the river, but this size gradation does not account for the sediment load of clay, silt, and sand-sized particles transported by the river as suspended load. Therefore, a range of assumed particle size gradations for the total sediment load was developed (Figure 6) and then applied to estimate the daily sediment inflow by particle size class. An example of this procedure is provided in Table 3, which is based on an assumed discharge of 1,000 cfs, a gravel and cobble yield of 40,000 $yd^3$/yr, the gravel and cobble load is 5% of the total sediment load, and the use of Equation 2.

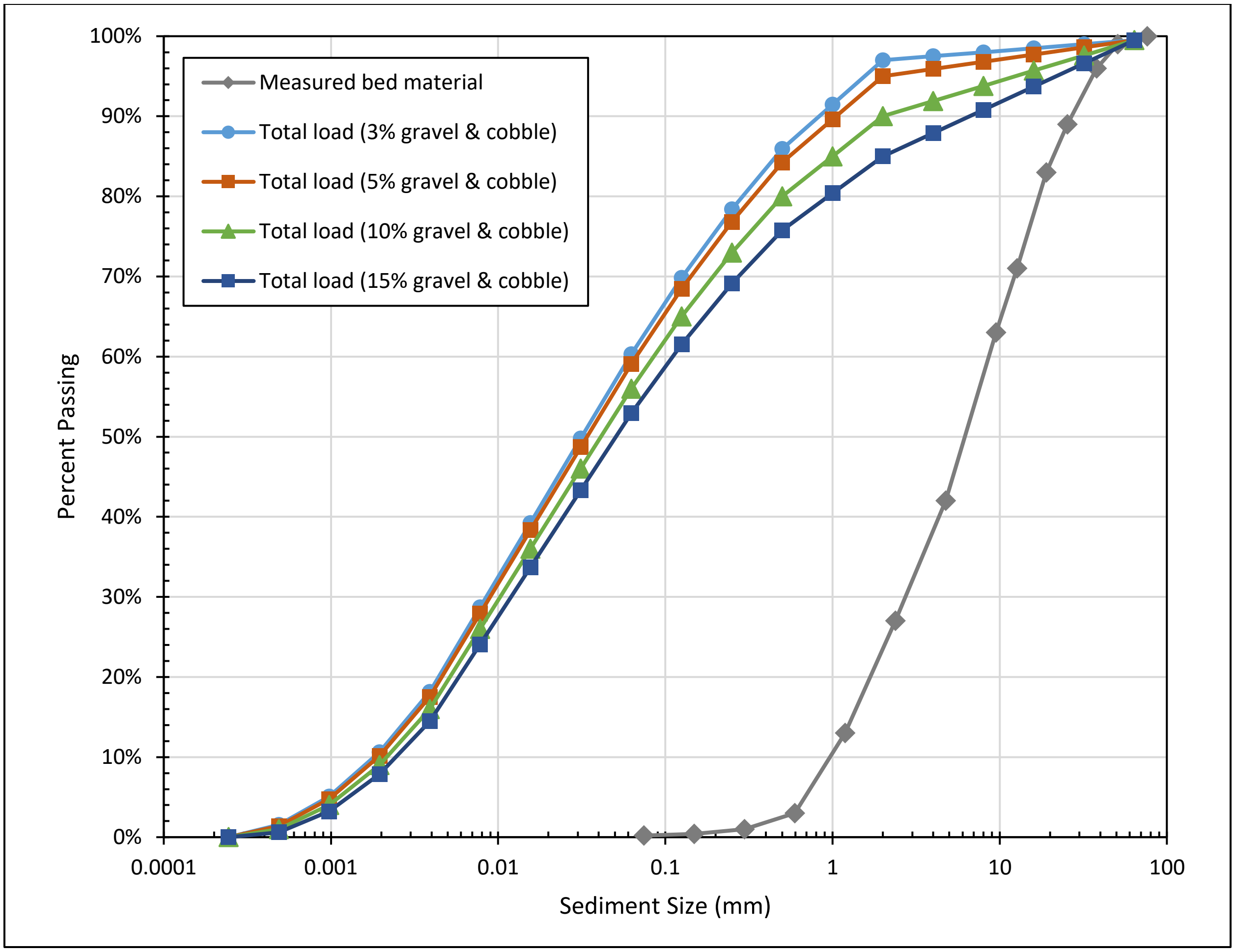



**Figure 6. Sediment particle size gradations for one measured bed material and a range of assumed gradations representing the total sediment load.**

**Table 2. Example computation of the daily sediment yield rate by particle size for a discharge of 1,000 cfs and the use of Equation 2.**

| Sediment Particle Size Class | Sediment Particle Diameter Range | | Portion in Size Class | Sediment Yield Rate |
|---|---|---|---|---|
| | (mm) | (mm) | | ($yd^3$/day) |
| Small cobbles | 64 | 128 | 0.50% | 46 |
| Very coarse gravel | 32 | 64 | 0.90% | 82 |
| Coarse gravel | 16 | 32 | 0.90% | 82 |
| Medium gravel | 8.0 | 16 | 0.90% | 82 |
| Fine gravel | 4.0 | 8.0 | 0.90% | 82 |
| Very fine gravel | 2.0 | 4.0 | 0.90% | 82 |
| Very coarse sand | 1.0 | 2.0 | 5.38% | 491 |
| Coarse sand | 0.50 | 1.0 | 5.38% | 491 |
| Medium sand | 0.25 | 0.50 | 7.38% | 673 |
| Fine sand | 0.13 | 0.25 | 8.38% | 765 |
| Very fine sand | 6.3E-2 | 0.13 | 9.38% | 856 |
| Coarse silt | 3.1E-2 | 6.3E-2 | 10.38% | 947 |

| Sediment Particle Size Class | Sediment Particle Diameter Range (mm) | (mm) | Portion in Size Class | Sediment Yield Rate (yd³/day) |
|---|---|---|---|---|
| Medium silt | 1.6E-2 | 3.1E-2 | 10.38% | 947 |
| Fine silt | 7.8E-3 | 1.6E-2 | 10.38% | 947 |
| Very fine silt | 3.9E-3 | 7.8E-3 | 10.38% | 947 |
| Coarse clay | 2.0E-3 | 3.9E-3 | 7.38% | 673 |
| Medim clay | 9.8E-4 | 2.0E-3 | 5.38% | 491 |
| Fine clay | 4.9E-4 | 9.8E-4 | 3.38% | 309 |
| Very fine clay | 2.4E-4 | 4.9E-4 | 1.38% | 126 |
| **Daily total** | **2.4E-4** | **128** | **100.00%** | **9,118** |

## 1.3 DIXON DIVERSION DAM FEATURE LAYOUT

The proposed Dixon Diversion consists of several components: the diversion dam, the tunnel intake, the forebay berm, and dike/sediment guide wall. Figure 7 presents the site layout with each of the components labeled. Between the diversion dam and the forebay berm is the diversion pool area (shaded in green), and the area leading from the forebay berm to the tunnel intake is the forebay pool area (shaded blue).

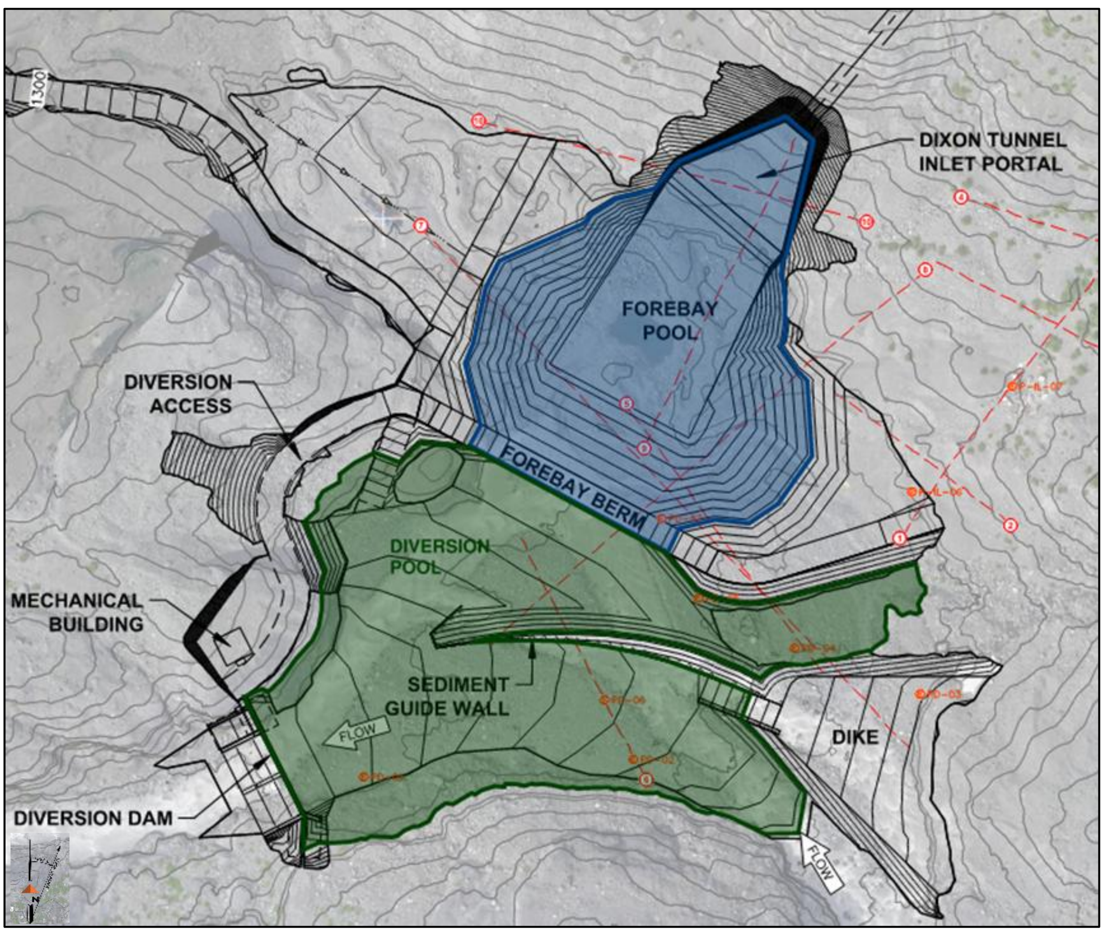



**Figure 7. Dixon Diversion site layout.**

Water from the Dixon Glacier enters the project site from the southwest and is guided into the diversion pool by the dike and sediment guide wall to direct inflow towards the diversion dam. The diversion pool is created by the ~25 ft tall diversion dam. The diversion dam includes two 32.8 ft (10 m) long by 21-ft tall Obermeyer gates with a maximum raised crest elevation of 1,276 ft and a minimum lowered elevation of 1,255 ft. The Obermeyer gates will be independently operable and are intended to be the primary means of sediment removal from behind the diversion and to pass large floods. Minimum instream flow (MIF) requirements will be delivered via a slide gate. Another slide gate (low-level bypass) is included to allow for an alternative means of MIF deliveries in conjunction with potential finer-grained sediment removal and operational flexibility during diversion or maintenance activities.

The MIF gate will not be used for passing sediment and is positioned with an invert elevation of 1,263 ft to ensure it will remain free of sediment and able to reliably deliver water downstream. The diversion pool floor elevation will vary with sedimentation, but sediment will be periodically flushed down to the minimum lowered Obermeyer gate elevation (elevation 1,255 ft).

A sediment guide wall will extend off the dike to direct flow and sediment towards the diversion and the Obermeyer gates. The wall creates a longer flow path for water going to the tunnel, increasing the hydraulic residence time and promoting sediment to deposit in front of the diversion. The sediment guide wall also helps concentrate velocity towards the diversion during sediment flushing operations.

The forebay berm divides the diversion pool from the forebay pool that leads to the tunnel intake. The purpose of the forebay berm is to ensure that water submerges the MIF gate before flowing into the tunnel. The adverse topographic grade up to the forebay sill also protects the tunnel's precast concrete liner from abrasion by promoting sediment deposition in the diversion pool area.

The Dixon Diversion site features are all related and function as a system to deliver water into the tunnel and to ensure the minimum instream flow requirements are met. For example, the forebay berm sill elevation ensures that the first water in the diversion pool will go through the MIF gate.

## 1.4 REPRESENTATIVE SITE HYDRAULICS

Figure 8 and Figure 9 present the two primary operating conditions of the diversion. In Figure 9, when one of the Obermeyer gates is down/opened, all of the inflow is routed through the diversion structure, creating riverine hydraulic conditions with shear stresses large enough to move cobbles. For reference, the tunnel design flow is 1,650 cfs. With an approximate MIF requirement of 100 cfs, a design inflow is 1,750 cfs, which is a high flow for a season, but less than a 2-yr flood peak. Note that the inflow design flood (IDF) for the Dixon Diversion is the 100-yr flood [5].

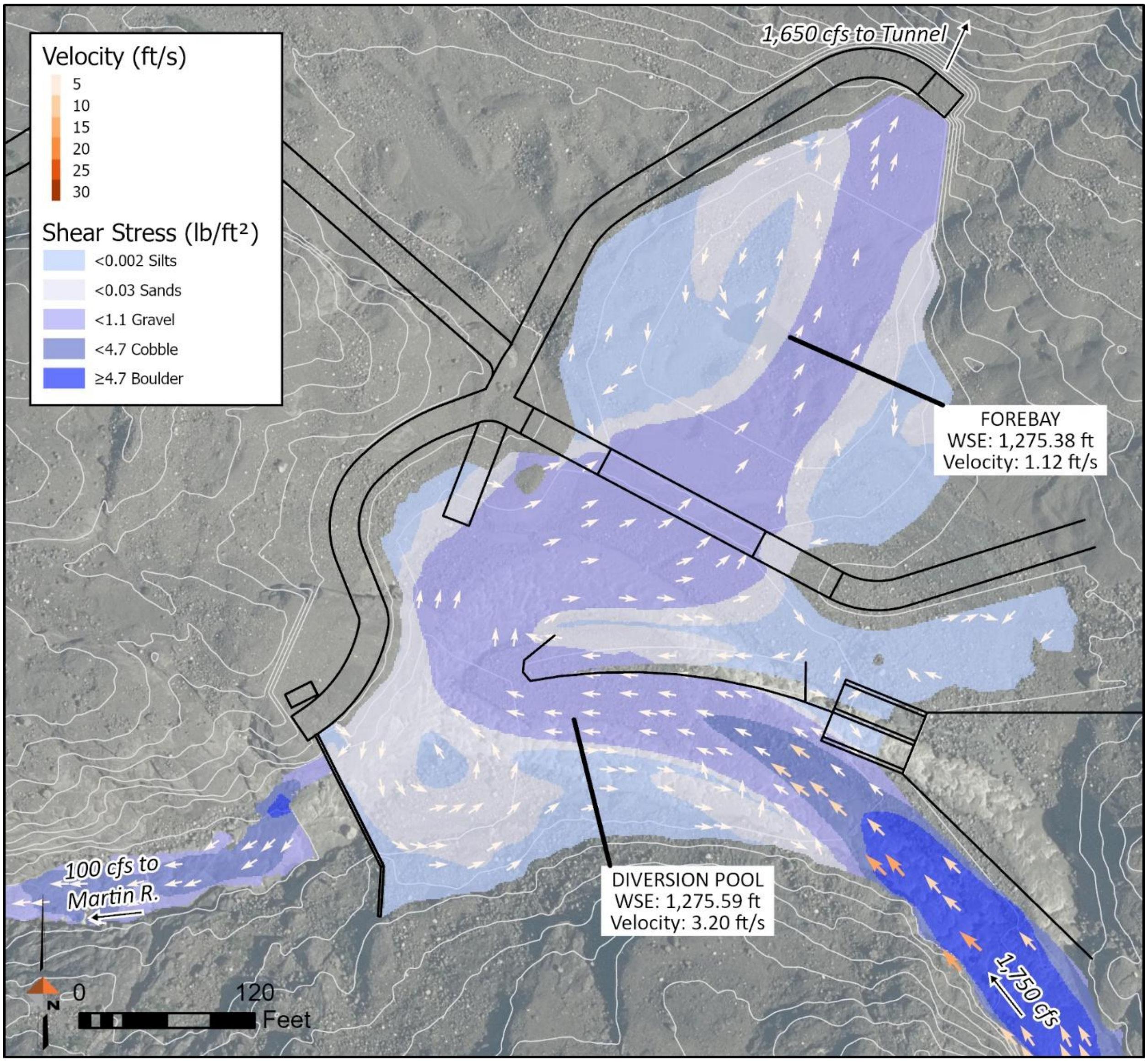



**Figure 8. Simulated flow-velocity vectors for a typical operation condition of 1,750 cfs inflow (1,650 cfs to the tunnel, 100 cfs to the MR from the MIF Gate).**

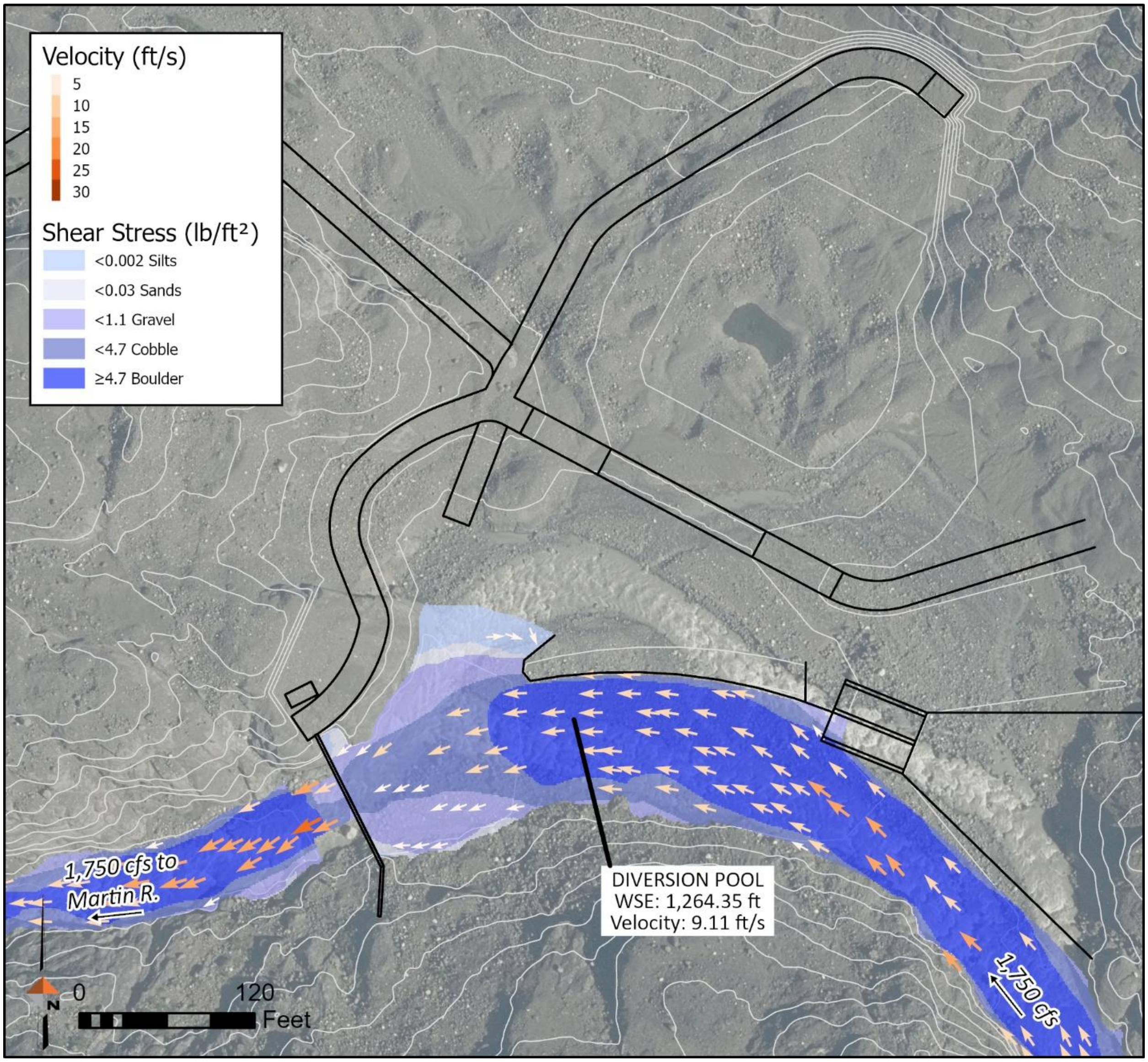



**Figure 9: Typical sediment flushing condition of 1,750 cfs inflow (all water through the Obermeyer Gates).**

## 1.5 SEDIMENT DEPOSITION

Sediment will accumulate in the diversion pool area in two primary size distributions. The larger coarse-grained materials (sands, gravels, cobbles, and boulders) will fall out early upon entering the diversion pool, forming a delta. The fine-grained sediments (clays, silts, and some sands) will continue suspended in the water to be deposited in eddies near the diversion dam and on the backside of the sediment guide wall. Fine-grained sediment will also flow past the diversion dam via the MIF releases and over the forebay berm into the tunnel; little to no sediment is expected to be deposited in the forebay pool.

Figure 10 presents how sediment is expected to deposit in the diversion pool, forming a delta. The delta will extend upstream and downstream as it grows. Assuming an average channel width of 100 ft and an upstream boundary elevation of 1,282 ft (~ the National Wildlife Refuge boundary), the maximum sediment storage volume is approximately 11,000 yd$^3$. Since the Dixon Diversion is expected to experience an average coarse sediment load of 40,000 yd$^3$/yr, the diversion pool will need to be flushed periodically to maintain operations. Delta formations are shown for three arbitrary deltas (Delta 1, Delta 2, and Delta 3), with foreset lengths of 50 ft, 75 ft, and 170 ft, respectively. See Appendix B for further details.

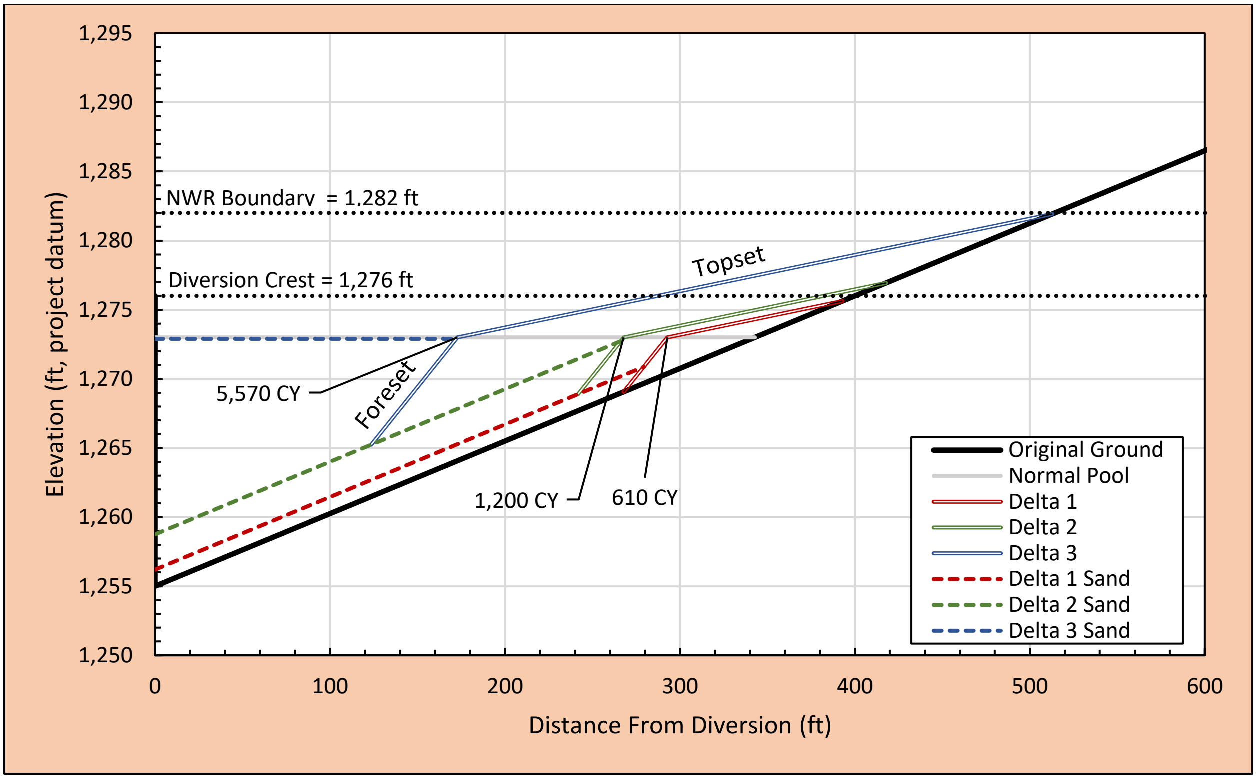



**Figure 10: Dixon Diversion sediment delta formation.**

# 2.0 GENERAL SETTLING BASIN MODELING STRATEGY

To quantify the estimated sedimentation volumes, gradations, and flushing frequency, a sediment settling basin model was developed with the following objectives:

- Estimate the rates of sediment deposition within the Dixon diversion pool
- Estimate the rates of downstream sediment delivery to the EFMR
- Estimate the rates of downstream sediment delivery to Bradley Lake
- Estimate the frequency that sediment will have to be hydraulically flushed or mechanically flushed (removed) from the Dixon diversion pool

The diversion pool upstream of the Dixon Diversion Dam will act as a settling basin for the incoming sediment load. Coarse sediment particles (coarse sand, gravel, cobbles, and boulders) will tend to deposit within the pool, whereas some of the finer particles (clay, silt, and fine to medium sand) may either deposit within the diversion pool or pass through without depositing, continuing down the EFMR or to Bradley Lake. Sediment settling-basin models were developed to simulate the deposition and passage of sediment particles entering the diversion pool. These simulations are based on daily input volumes of water and sediment, by particle size class, entering the pool (Table 3).

**Table 3. Sediment size classification and particle size range (based on Lane et al. 1947 [6]).**

| Sediment Particle Size Class | Sediment Particle Diameter Range | | Geometric Mean Diameter | |
|---|---|---|---|---|
| | (mm) | (mm) | (mm) | (ft) |
| Small cobbles | 64 | 130 | 91 | 0.30 |
| Very coarse gravel | 32 | 64 | 45 | 0.15 |
| Coarse gravel | 16 | 32 | 23 | 7.4E-2 |
| Medium gravel | 8.0 | 16 | 11 | 3.7E-2 |
| Fine gravel | 4.0 | 8.0 | 5.7 | 1.9E-2 |
| Very fine gravel | 2.0 | 4.0 | 2.8 | 9.3E-3 |
| Very coarse sand | 1.0 | 2.0 | 1.4 | 4.6E-3 |
| Coarse sand | 0.50 | 1.0 | 0.71 | 2.3E-3 |
| Medium sand | 0.25 | 0.50 | 0.35 | 1.2E-3 |
| Fine sand | 0.13 | 0.25 | 0.18 | 5.8E-4 |
| Very fine sand | 6.3E-2 | 0.13 | 8.8E-2 | 2.9E-4 |
| Coarse silt | 3.1E-2 | 6.3E-2 | 4.4E-2 | 1.5E-4 |
| Medium silt | 1.6E-2 | 3.1E-2 | 2.2E-2 | 7.3E-5 |
| Fine silt | 7.8E-3 | 1.6E-2 | 1.1E-2 | 3.6E-5 |
| Very fine silt | 3.9E-3 | 7.8E-3 | 5.5E-3 | 1.8E-5 |
| Coarse clay | 2.0E-3 | 3.9E-3 | 2.8E-3 | 9.1E-6 |
| Medim clay | 9.8E-4 | 2.0E-3 | 1.4E-3 | 4.5E-6 |
| Fine clay | 4.9E-4 | 9.8E-4 | 6.9E-4 | 2.3E-6 |
| Very fine clay | 2.4E-4 | 4.9E-4 | 3.5E-4 | 1.1E-6 |

## 2.1 MODEL AREAS

Sediment settling-basin models were applied to the diversion pool in two parts to estimate the sedimentation rates within the pool (Figure 11).

1. **Front Side model area:** From the EFMR diversion pool inlet, along the sediment guide wall to the Dixion Diversion Dam.
2. **Back Side model area:** From the downstream end of the sediment guide wall to the forebay berm sill.

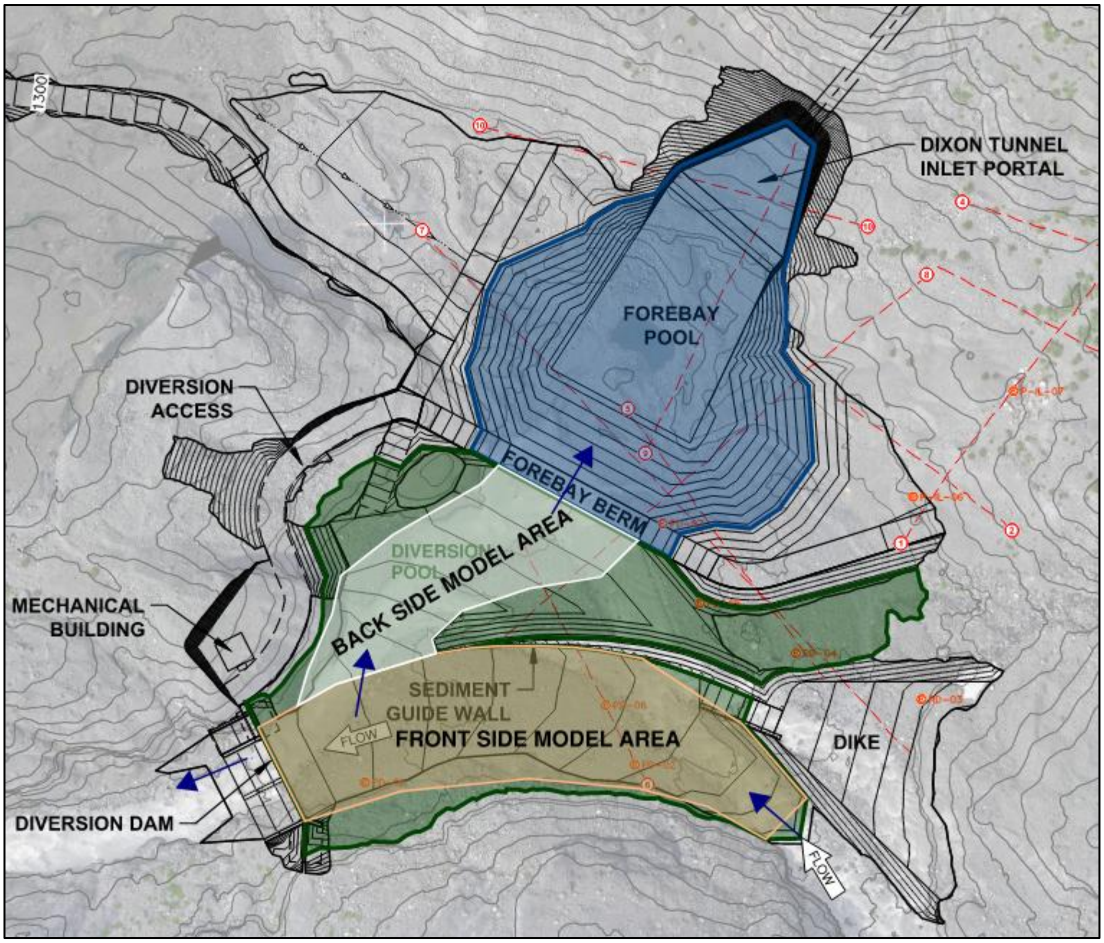



**Figure 11. Layout of sediment settling basin models.**

For each model area, sediment trap efficiencies were estimated for a range of EFMR inflow rates and sediment settling lengths. These sediment trap efficiencies were then applied to the estimated sediment inflow rates.

Sediment loads from the Dixon Glacier are the upstream boundary input to the front side of the sediment guide wall model area. A portion of the sediment outflow from the front side area was simulated to be released with the MIF deliveries, and the remainder flows to the back side model area. Uncaptured sediment will be conveyed through the tunnel to Bradley Lake.

## 2.2 PROBABILITY DISTRIBUTIONS OF KEY MODEL INPUTS

In summary, there are three input variables for numerical modeling of diversion pool sedimentation:

- Average annual gravel and cobble load of the Dixon Glacier
- Gravel and cobble load portion of the total sediment load
- Equation 1 sediment-discharge exponent, *b*

Even though specific values for these key model inputs are not known, probability distributions for these inputs can be assumed based on professional judgment from experience in other glacier and river systems (Figure 12, Figure 13, and Figure 14). Using these probability distributions, Monte Carlo model simulations were performed to estimate the likely rates of sediment deposition, sediment delivery to the downstream river, sediment delivery to Bradley Lake, and the frequency that sediment will need to be flushed from the diversion pool [7].

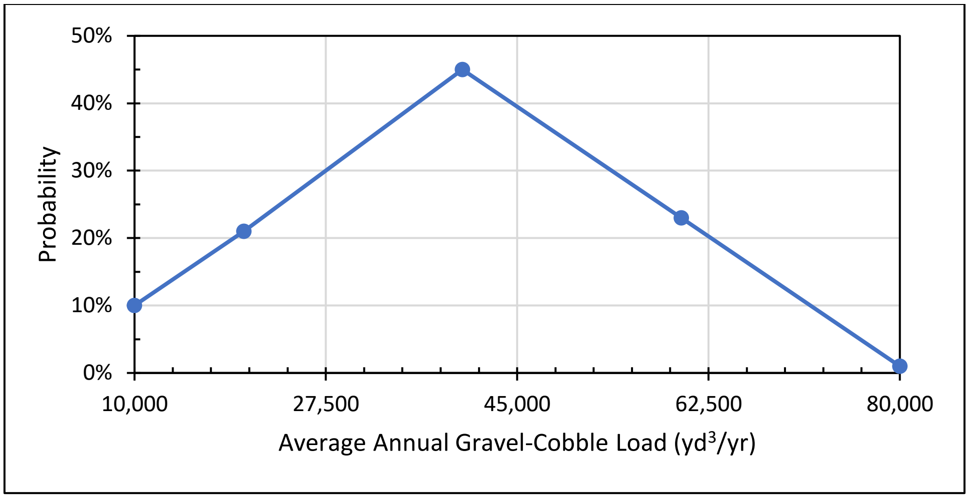



**Figure 12. Assumed probability distribution for the average annual gravel and cobble load of the East Fork Martin River.**

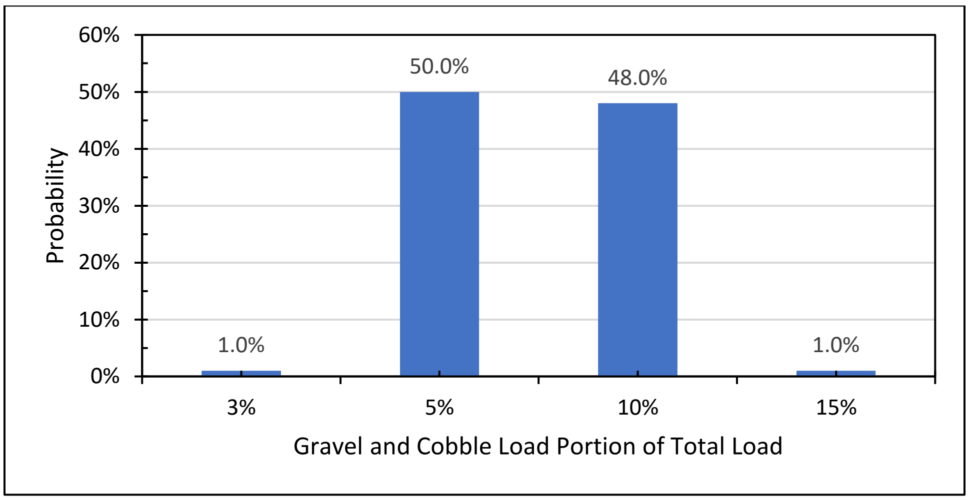



**Figure 13. Assumed probability distribution for the gravel and cobble load portion of the total sediment load for the East Fork of the Martin River.**

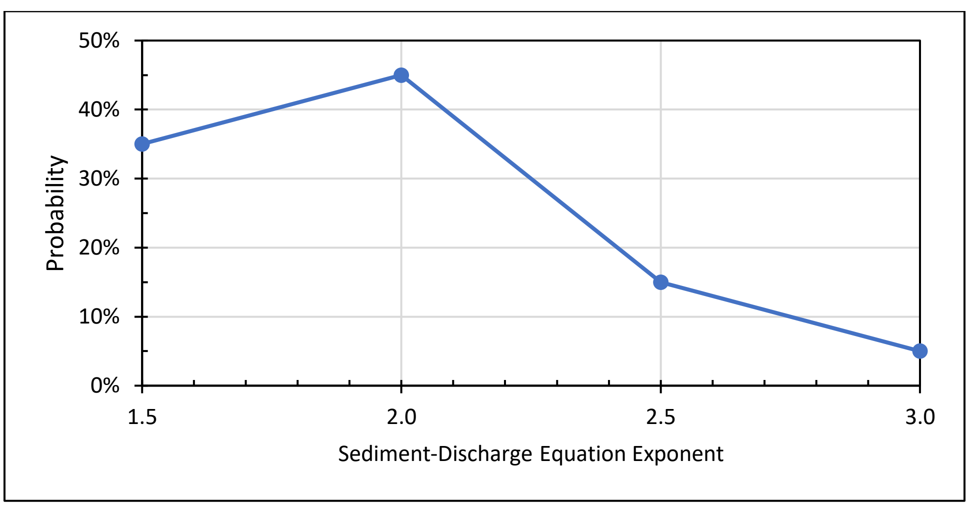



**Figure 14. Assumed probability distribution for the sediment-discharge equation exponent for the East Fork of the Martin River.**

# 3.0 SETTLING BASIN MODELING EQUATIONS

The sediment setting basin model begins with mass balance equations. The sediment deposition rate equals the sediment inflow rate multiplied by the sediment trap efficiency (Equation 3).

$$\boldsymbol{Q_{(s-dep)} = Q_{(s-in)}\, P} \quad (3)$$

$Q_{(s-dep)}$ = sediment deposition rate (yd$^3$/day),
$Q_{(s-in)}$ = sediment inflow rate (yd$^3$/day),
*P* = sediment trap efficiency (%),

The sediment outflow rate equals the sediment inflow rate multiplied by one minus the sediment trap efficiency (Equation 4).

$$\boldsymbol{Q_{(s-out)} = Q_{(s-in)}\,(1 - P)} \quad (4)$$

$Q_{(s-out)}$ = sediment outflow rate (yd$^3$/day),

The sediment trap efficiency is a function of the ratio of particle fall velocity multiplied by the settling basin length, divided by the product of the average flow velocity and the average flow depth (Equation 5) [8]:

$$\boldsymbol{P = \left(1 - \frac{1}{e^{\left(\frac{1.005\,\omega\, L}{V\ D}\right)}}\right)} \quad (5)$$

Where:
*ω* = sediment particle-fall velocity (ft/s),
*L* = settling basin length (ft),
*V* = average water discharge velocity through settling basin (ft/s),
*D* = average settling basin flow depth (ft),

The average flow rate through the settling basin is equal to the discharge rate divided by the cross-sectional area of discharge, where the cross-sectional area is equal to the average basin width multiplied by the average basin depth (Equation 6):

$$\boldsymbol{V = \frac{Q_w}{W\ D}} \quad (6)$$

Where:
$Q_w$ = inflow discharge rate (cfs),
*W* = average settling basin width (ft),

If the discharge, and the average basin width and depth (Equation 6), are substituted for velocity in Equation 5, then the sediment trap efficiency equation can be rewritten (Equation 7):

$$\boldsymbol{P = \left(1 - \frac{1}{e^{\left(\frac{1.005\,\omega\, A_s}{Q_w}\right)}}\right)} \quad (7)$$

Where:
$A_s$ = surface area of the diversion pool (ft$^2$) $(A_s = L\,W)$,

Rubey (1933) developed an equation to predict sediment particle fall velocity for gravel, sand, and silt-sized particles [9]. For gravel-sized sediment (particle diameter greater than 2 mm), the settling velocity is a function of the particle diameter (Equation 8):

$$\omega = 6.01\, d^{1/2} \tag{8}$$

For sand, silt, and clay-sized particles (< 2 mm), the settling velocity is a function of the particle diameter and the specific weight of sediment (Equation 9):

$$\omega = F\left[dg\left(\frac{\lambda_s - \lambda}{\lambda}\right)\right]^{1/2} \tag{9}$$

Where:

*F* = 0.79 for very coarse sand (particle diameters between 1 and 2 mm) settling in water temperatures between 50 °F and 70°F

*g* = gravitational acceleration (ft/s$^2$),

*λ* = specific weight of water (62.4 lbs/ft$^3$),

$\lambda_s$ = specific weight of sediment (165.4 lbs/ft$^3$, assuming a specific gravity of 2.65),

To simplify this modeling effort, the factor, *F*, is kept equal to 0.79 for temperatures colder than 50 °F.

For finer sand and silt-sized sediment (particle diameters less than 1 mm), the settling velocity is also a function of the viscosity of the water and sediment mixture, and the factor, *F*, is computed using Equation 10:

$$F = \left[\frac{2}{3} + \frac{36\,\nu^2}{g\,d^3\left(\lambda_s/\lambda - 1\right)}\right]^{1/2} - \left[\frac{36\,\nu^2}{g\,d^3\left(\lambda_s/\lambda - 1\right)}\right]^{1/2} \tag{10}$$

Where:

*v* = kinematic viscosity of the water-sediment mixture (ft$^2$/s)

The equation to compute the fall velocity factor, *F*, (Equation 10) can be simplified into Equation 11 and Equation 12:

$$F = \left[\frac{2}{3} + c_v\right]^{1/2} - [c_v]^{1/2} \tag{11}$$

$$c_v = \left[\frac{36\,\nu^2}{g\,d^3\,\left(\lambda_s/\lambda\right) - 1}\right] \tag{12}$$

The kinematic viscosity of the water-sediment mixture is the same as that of water when the sediment concentrations are well below 10,000 mg/L [10]. The viscosity of water is published in tables, but can be estimated as a function of water temperature using a regression equation (Figure 15 and Equation 13):

$$\nu = \left(2.949 \times 10^{-9}\right) T^2 - \left(5.276 \times 10^{-7}\right) T + 3.312 \times 10^{-5} \tag{13}$$

Where:

*T* = water temperature (°F),

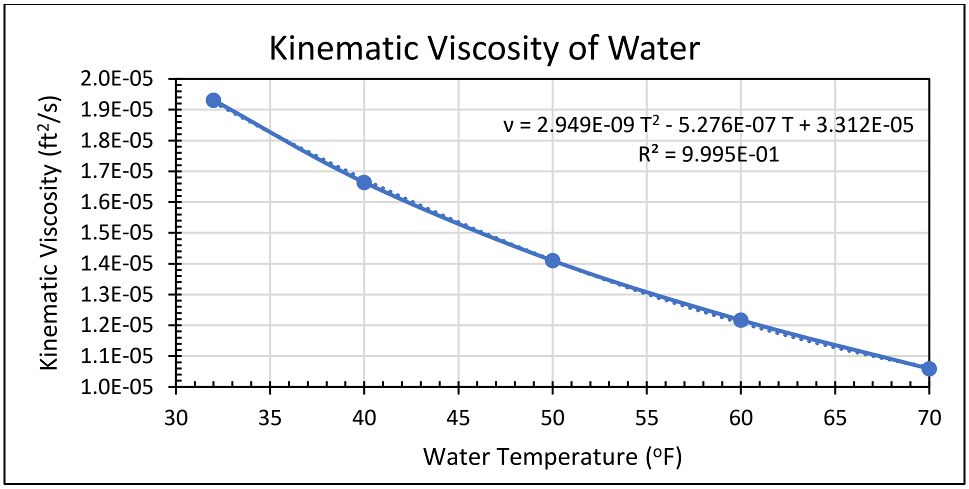



**Figure 15. Kinematic viscosity decreases with water temperature.**

# 4.0 SETTLING BASIN MODEL APPLICATION

The sediment settling basin model was applied 1,000 times using different combinations of input assumptions based on the probability distributions of those inputs. The full range of probable inputs was simulated; as such, input values with the greatest probability were simulated more frequently than inputs of a lesser probability.

For each simulation, a spreadsheet was used to apply the model in multiple steps. First, daily sediment loads from the Dixon Glacier were computed for the 46-year period from 1980 through 2025. This was accomplished by assuming an average annual gravel and cobble load and the percentage of the total sediment load that is gravel and cobble. From these two input choices, the total average annual sediment load is computed. Equation 1 is then applied to the daily discharge values to compute the daily sediment loads. The exponent (*b*) of Equation 1 was assumed (values between 1.5 and 3.0), and the coefficient (*a*) was back calculated so that the average annual sediment load (computed from the daily sediment loads) matched the assumed average annual sediment load (Figure 5).

## 4.1 COMPUTATION OF SEDIMENT TRAP EFFICIENCIES

Diversion pool sediment trap efficiencies were then computed for each sediment grain size, for a range of river discharges (in increments of 250 cfs between 250 and 1,750 cfs), and for a range of settling lengths (50 to 350 ft, in increments of 50 ft). An example calculation for the sediment guide wall portion of the diversion pool is presented in Table 4 for an assumed discharge of 1,000 cfs, a settling length of 200 ft, and an average settling width of 100 ft. For this example, all inflowing cobbles, gravel, and very coarse sand are predicted to deposit within the diversion pool. High percentages of coarse and medium sand (98% and 87%) are expected to deposit, while much lower percentages of fine and very fine sand (63% and 36%) are expected to deposit. A small portion of the inflowing silt-sized particles (18% to 1.5%) are expected to deposit. An even smaller portion of the inflowing clay-sized particles (0.6% to 0.05%) are expected to deposit.

**Table 4. Example sediment model results with parameters defined above.**

| Sediment Particle Size Class | Sediment Particle Diameter Range | | Geometric Mean Diameter | Fall Velocity Factors | | Fall Velocity, $\omega$ | Sediment Trap Efficiency, $P$ |
|---|---|---|---|---|---|---|---|
| | (mm) | (mm) | (mm) | $C_v$ | $F$ | (ft/s) | |
| Small cobbles | 64 | 130 | 91 | 9.3E-9 | 0.79 | 3.28 | 100% |
| Very coarse gravel | 32 | 64 | 45 | 7.4E-8 | 0.79 | 2.32 | 100% |
| Coarse gravel | 16 | 32 | 23 | 5.9E-7 | 0.79 | 1.64 | 100% |
| Medium gravel | 8.0 | 16 | 11 | 4.7E-6 | 0.79 | 1.16E | 100% |
| Fine gravel | 4.0 | 8.0 | 5.7 | 3.8E-5 | 0.79 | 0.82 | 100% |
| Very fine gravel | 2.0 | 4.0 | 2.8 | 3.0E-4 | 0.79 | 0.58 | 100% |
| Very coarse sand | 1.0 | 2.0 | 1.4 | 4.9E-2 | 0.79 | 0.39 | 100% |
| Coarse sand | 0.50 | 1.0 | 0.71 | 1.4E-1 | 0.52 | 0.18 | 98% |
| Medium sand | 0.25 | 0.50 | 0.35 | 3.9E-1 | 0.40 | 0.10 | 87% |
| Fine sand | 0.13 | 0.25 | 0.18 | 1.1 | 0.28 | 4.9E-2 | 63% |
| Very fine sand | 6.3E-2 | 0.13 | 8.8E-2 | 3.2 | 0.18 | 2.2E-2 | 36% |
| Coarse silt | 3.1E-2 | 6.3E-2 | 4.4E-2 | 8.9 | 0.11 | 9.6E-3 | 18% |
| Medium silt | 1.6E-2 | 3.1E-2 | 2.2E-2 | 25 | 6.6E-2 | 4.1E-3 | 8% |
| Fine silt | 7.8E-3 | 1.6E-2 | 1.1E-2 | 71 | 3.9E-2 | 1.7E-3 | 3% |
| Very fine silt | 3.9E-3 | 7.8E-3 | 5.5E-3 | 2.0E2 | 2.3E-2 | 7.3E-4 | 1.5% |
| Coarse clay | 2.0E-3 | 3.9E-3 | 2.8E-3 | 5.7E2 | 1.4E-2 | 3.1E-4 | 0.6% |
| Medim clay | 9.8E-4 | 2.0E-3 | 1.4E-3 | 1.6E3 | 8.3E-3 | 1.3E-4 | 0.26% |
| Fine clay | 4.9E-4 | 9.8E-4 | 6.9E-4 | 4.6E3 | 4.9E-3 | 5.4E-5 | 0.11% |
| Very fine clay | 2.4E-4 | 4.9E-4 | 3.5E-4 | 1.3E4 | 2.9E-3 | 2.3E-5 | 0.05% |

Sediment that does not deposit along the guide wall will either pass to the downstream river channel or continue being transported through the diversion pool toward the forebay berm sill. A model assumption is that sediment will divert in proportion to the discharge (e.g., if one-quarter of the flow leaving the front side sediment guide wall model area is released through a MIF gate, then one-quarter of the sediment leaving that model area will also be released through the MIF gate).

$$\boldsymbol{Q_{(s-river)} = Q_{(s-out)} \left(\frac{Q_{w-river}}{Q_{w-out}}\right)} \tag{14}$$

Where:

$Q_{(s-river)}$ = sediment discharge rate to downstream river ($yd^3$/day),

$Q_{(s-out)}$ = sediment outflow rate from the front side portion of the diversion pool ($yd^3$/day),

$Q_{(w-river)}$ = water discharge rate to downstream river (cfs),

$Q_{(w-out)}$ = water discharge rate from the front side portion of the diversion pool (cfs)

Sediment trap efficiencies were also computed for the back side of the guide wall area of the pool for a range of sediment grain sizes and river discharges. For the back side portion, the settling length was held constant at 200 ft, and the average basin width was set to 90 ft. An example calculation for the back side portion is presented in Table 5 for an assumed discharge of 900 cfs (1,000 cfs inflow to the diversion with an assumed 100 cfs MIF release and 900 cfs going through the back side model area). For this example, all inflowing cobbles, gravel, and very coarse sand are predicted to have already deposited within the front side area of the diversion pool. High percentages of coarse and medium sand (98% and 87%) are expected to deposit along the back side, while lower percentages of fine and very fine sand (63% and 36% are expected to deposit. A small portion of the inflowing silt-sized particles (18% to 1.5%) are expected to deposit within the back side of the diversion pool. An even smaller portion of the inflowing clay-sized particles (0.6% to 0.05%) than the silt sized particles are expected to deposit within the back side of the pool.

**Table 5. Example model calculation of sediment trap efficiency for the back side of the pool, assuming a discharge of 900 cfs, settling length of 200 ft, and an average settling width of 90 ft.**

| Sediment Particle Size Class | Sediment Particle Diameter Range | | Geometric Mean Diameter | Fall Velocity Factors | | Fall Velocity, $\omega$ | Sediment Trap Efficiency, $P$ |
|---|---|---|---|---|---|---|---|
| | (mm) | (mm) | (mm) | $C_v$ | $F$ | (ft/s) | |
| Small Cobbles | 64 | 128 | 90.510 | 9.26E-09 | 7.90E-01 | 3.28E+00 | 100% |
| Very coarse gravel | 32 | 64 | 45.255 | 7.41E-08 | 7.90E-01 | 2.32E+00 | 100% |
| Coarse gravel | 16 | 32 | 22.627 | 7.70E-04 | 7.90E-01 | 1.64E+00 | 100% |
| Medium gravel | 8 | 16 | 11.314 | 2.18E-03 | 7.90E-01 | 1.16E+00 | 100% |
| Fine gravel | 4 | 8 | 5.657 | 6.16E-03 | 7.90E-01 | 8.19E-01 | 100% |
| Very fine gravel | 2 | 4 | 2.828 | 1.74E-02 | 7.90E-01 | 5.79E-01 | 100% |
| Very coarse sand | 1 | 2 | 1.414 | 4.93E-02 | 7.90E-01 | 3.92E-01 | 100% |
| Coarse sand | 0.5 | 1 | 0.707 | 1.39E-01 | 5.24E-01 | 1.84E-01 | 98% |
| Medium sand | 0.25 | 0.5 | 0.354 | 3.94E-01 | 4.02E-01 | 9.98E-02 | 87% |
| Fine sand | 0.125 | 0.25 | 0.177 | 1.12E+00 | 2.79E-01 | 4.89E-02 | 63% |
| Very fine sand | 0.0625 | 0.125 | 0.088 | 3.15E+00 | 1.79E-01 | 2.22E-02 | 36% |
| Coarse silt | 0.0313 | 0.0625 | 0.044 | 8.92E+00 | 1.10E-01 | 9.62E-03 | 18% |
| Medium silt | 0.0156 | 0.0313 | 0.022 | 2.52E+01 | 6.59E-02 | 4.09E-03 | 8% |
| Fine silt | 0.0078 | 0.0156 | 0.011 | 7.14E+01 | 3.94E-02 | 1.73E-03 | 3% |
| Very fine silt | 0.0039 | 0.0078 | 0.006 | 2.02E+02 | 2.34E-02 | 7.27E-04 | 1.5% |
| Coarse clay | 0.0020 | 0.0039 | 0.003 | 5.71E+02 | 1.39E-02 | 3.06E-04 | 0.6% |
| Medim clay | 0.0010 | 0.0020 | 0.001 | 1.61E+03 | 8.29E-03 | 1.29E-04 | 0.26% |
| Fine clay | 0.0005 | 0.0010 | 0.001 | 4.57E+03 | 4.93E-03 | 5.41E-05 | 0.11% |
| Very fine clay | 0.00024 | 0.0005 | 0.000 | 1.29E+04 | 2.93E-03 | 2.28E-05 | 0.05% |

## 4.2 COMPUTATION OF DIVERSION POOL SEDIMENTATION

Sedimentation rates were then computed for the front and back side areas of the diversion pool. Sedimentation rates were computed for the same range of discharges, settling lengths, and grain sizes as the sediment trap efficiency computations. An example calculation of sedimentation is presented in Table 6 for an assumed discharge of 1,000 cfs, settling lengths of 200 ft along the front and back side areas. The average settling basin widths were 100 ft on the front side and 90 ft on the back side. For this example, 33% of the inflowing sediment is predicted to deposit within the diversion pool on the front side. Most of this sedimentation is predicted to be cobble, gravel, and very coarse to fine sand. A portion of the very fine sand (36%) and some of the silt sizes (18% to 1%) are expected to deposit along the front side of the sediment guide wall. Very little, if any, clay size particles are expected to deposit within the front side area.

Of the sediments that transport through the front side along the guide wall (sand, silt, and clay-sized particles), 7% are predicted to be discharged downstream to the EFMR through the MIF gate (i.e., 100 cfs (10%) of the inflow of 1,000 cfs will be discharged downstream).

Of the sediments that transport through the front side (sand, silt, and clay-sized particles) and continue through the back side area toward the forebay berm, 12% are predicted to deposit within the back side portion of the diversion pool. Most of the sedimentation is predicted to be sand (100% to 36%). Some silt is also expected to deposit in the back side area (18% to 1%). Little if any clay-sized particles are predicted to deposit.

Of the sediment particles that inflow to the diversion pool, 52% are predicted to flow into the diversion tunnel to Bradley Lake. The sediment that flows to Bradley Lake will include small amounts of medium, fine, and very fine sand (2%, 13%, and 7%). Most of the silt and clay-size particles entering the pool are predicted to be diverted through the tunnel, including 61% to 87% of the silt and 89%to 90% of the clay particles.

**Table 6. Example calculation of sediment inflow rates, sedimentation rates, and sediment outflow rates for Dixon Diversion at a discharge inflow rate of 1,000 cfs.**

| Sediment Particle Size Class | Portion in Size Class | Sediment Inflow Rate ($yd^3$/day) | Front Side Sedimentation Rate ($yd^3$/day) | Sediment Discharge Rate to EFMR ($yd^3$/day) | Back Side Sedimentation Rate ($yd^3$/day) | Sediment Discharge Rate to Tunnel ($yd^3$/day) |
|---|---|---|---|---|---|---|
| Small Cobbles | 0.50% | 46 | 46 | 0.0 | 0 | 0 |
| Very coarse gravel | 0.90% | 82 | 82 | 0.0 | 0 | 0 |
| Coarse gravel | 0.90% | 82 | 82 | 0.0 | 0 | 0 |
| Medium gravel | 0.90% | 82 | 82 | 0.0 | 0 | 0 |
| Fine gravel | 0.90% | 82 | 82 | 0.0 | 0 | 0 |
| Very fine gravel | 0.90% | 82 | 82 | 0.0 | 0 | 0 |
| Very coarse sand | 5.38% | 491 | 491 | 0.0 | 0 | 0 |
| Coarse sand | 5.38% | 491 | 479 | 1.2 | 11 | 0 |
| Medium sand | 7.38% | 675 | 583 | 9.1 | 71 | 11 |
| Fine sand | 8.38% | 765 | 479 | 28.6 | 161 | 96 |
| Very fine sand | 9.38% | 856 | 308 | 54.8 | 177 | 316 |
| Coarse silt | 10.38% | 947 | 166 | 78.0 | 123 | 579 |
| Medium silt | 10.38% | 947 | 75 | 87.2 | 62 | 723 |
| Fine silt | 10.38% | 947 | 32 | 91.5 | 28 | 795 |
| Very fine silt | 10.38% | 947 | 14 | 93.3 | 12 | 828 |
| Coarse clay | 7.38% | 673 | 4 | 66.9 | 4 | 599 |
| Medim clay | 5.38% | 491 | 1 | 49.0 | 1 | 440 |
| Fine clay | 3.38% | 309 | 0 | 30.8 | 0 | 277 |
| Very fine clay | 1.38% | 126 | 0 | 12.6 | 0 | 114 |
| **Total Sediment Rates** | | **9,118** | **3,088** | **603** | **651** | **4,776** |

## 4.3 DIVERSION POOL SEDIMENT FLUSHING

The diversion pool sediment will need to be periodically flushed downstream to the EFMR. Hydraulic flushing will be accomplished by lowering the Obermeyer spillway gates when inflows are sufficiently high to flush the sedimentation from the front side area. Sedimentation within the back side area of the diversion pool will need to be mechanically flushed with excavation equipment during periods of low river discharge or during a hydraulic flush. Sediment will be mechanically moved to the stream channel just upstream from the diversion dam slide gates, or Obermeyer spillway gates, for hydraulic flushing downstream. The settling basin model simulates when the diversion pool is hydraulically flushed by numerically accumulating the computed daily sedimentation volumes.

The model numerically triggers a hydraulic flush of sediment along the front side of the sediment guide wall when both of the following conditions are met:

1. When the cumulated sedimentation volume equals or exceeds 9,900 $yd^3$ (90% of the sediment storage capacity along front side of the sediment guide wall, which is estimated to be 11,000 $yd^3$).
2. When discharge flowing into the diversion pool equals or exceeds 200 cfs.

The model incorporates the assumption that each hydraulic sediment flush is completed within a single day. Estimates of the time required to hydraulically flush sediment are discussed in Section 5.2.

An example application of the hydraulic flushing criteria is presented in Figure 16. In this example, 2021 hydrology data were used to simulate the frequency of sediment flushing. The diversion pool starts the year with nearly 3,800 $yd^3$ of sediment along the front side of the diversion pool. By June 7$^{th}$, the projected sedimentation volume exceeds 9,900 $yd^3$, the inflow discharge exceeds 200 cfs, and the sediment is numerically flushed downstream. Sedimentation then accumulates over the next 16 days until the pool is again flushed on June 24$^{th}$. The cycle of sedimentation and flushing is repeated 18 more times for a total of 20 times during the year. For this simulation, the number of days between hydraulic sediment flushes averages 5.2 days. There are also eight occurrences where there are just 3 days between hydraulic sediment flushes. For the simulated year (2021), a total of 233,000 $yd^3$ of sediment were hydraulically flushed downstream, with an average of 11,700 $yd^3$ per flush.

Simulation of this example year ends with just over 2,700 $yd^3$ of sediment trapped in the front side area of the sediment guide wall (the model did not trigger an end of season flush flushed because the diversion inflows were less than 200 cfs).

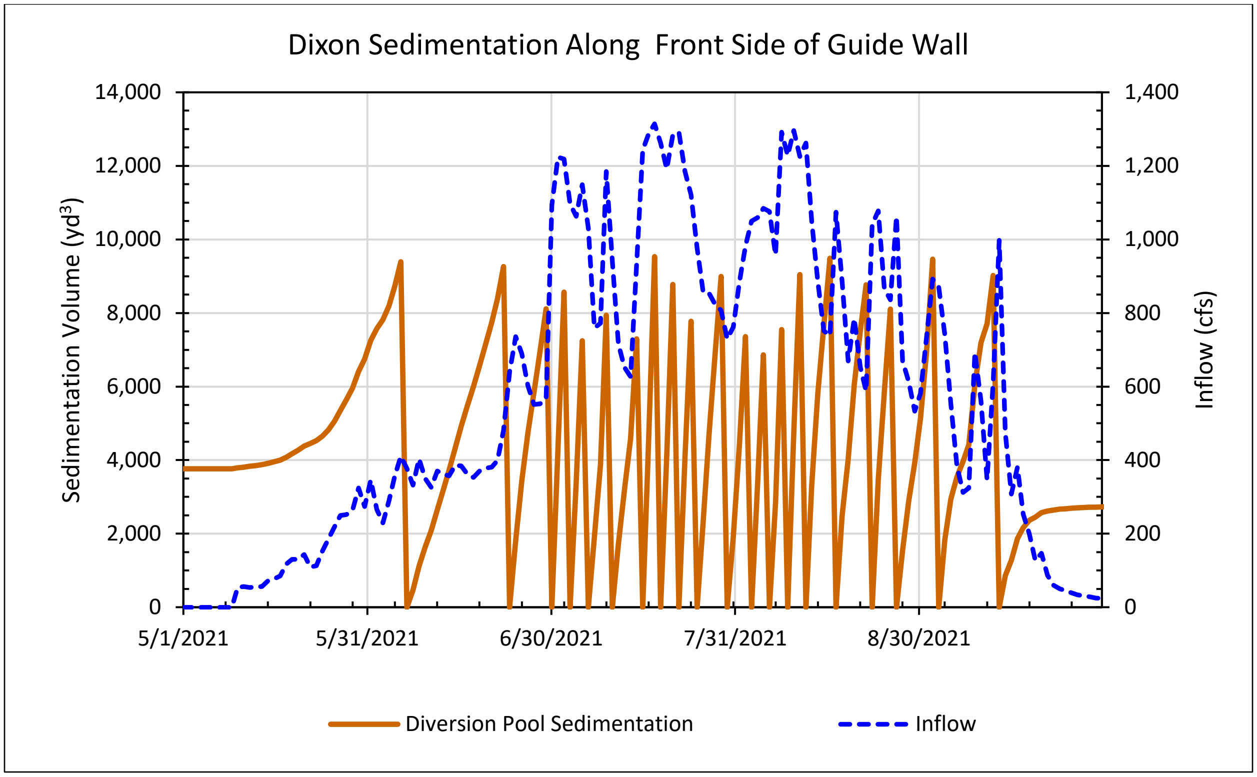



**Figure 16. Example application of hydraulic sediment flushing criteria during 2021, where sedimentation and inflow are tracked daily.**

Mechanical sediment flushes from the back side area of the diversion pool are assumed prior to the water diversion season, which is expected to start on May 15th of each year. In addition, a mechanical flush is assumed to occur when the cumulated sedimentation volume in the back side area of the diversion pool equals or exceeds 2,700 $yd^3$ (90% of the sediment storage capacity of the back side area, which is estimated to be 3,000 $yd^3$). An example application of the mechanical flushing criteria is presented in Figure 17. This example also uses 2021 hydrology data to simulate the frequency of mechanical sediment flushing. In this example, the back side area of the diversion pool starts the year with nearly 1,600 $yd^3$ of sediment. As scheduled, a mechanical sediment flush of the back side area occurs on May 15th. Sedimentation then accumulates along the back side over the next 41 days until this area of the pool is again mechanically flushed on June 25th. The cycle of sedimentation and flushing is repeated 16 more times, for a total of 17 times during the year. For this simulation, the number of days between mechanical sediment flushes averages 7.6 days. There are also four occurrences where there are just three days between mechanical sediment flushes. For the simulated year, a total of 48,700 $yd^3$ of sediment were mechanically flushed downstream, with an average of 2,900 $yd^3$ per flush. Simulation of this example year ends with 250 $yd^3$ of sediment trapped within the back side area.

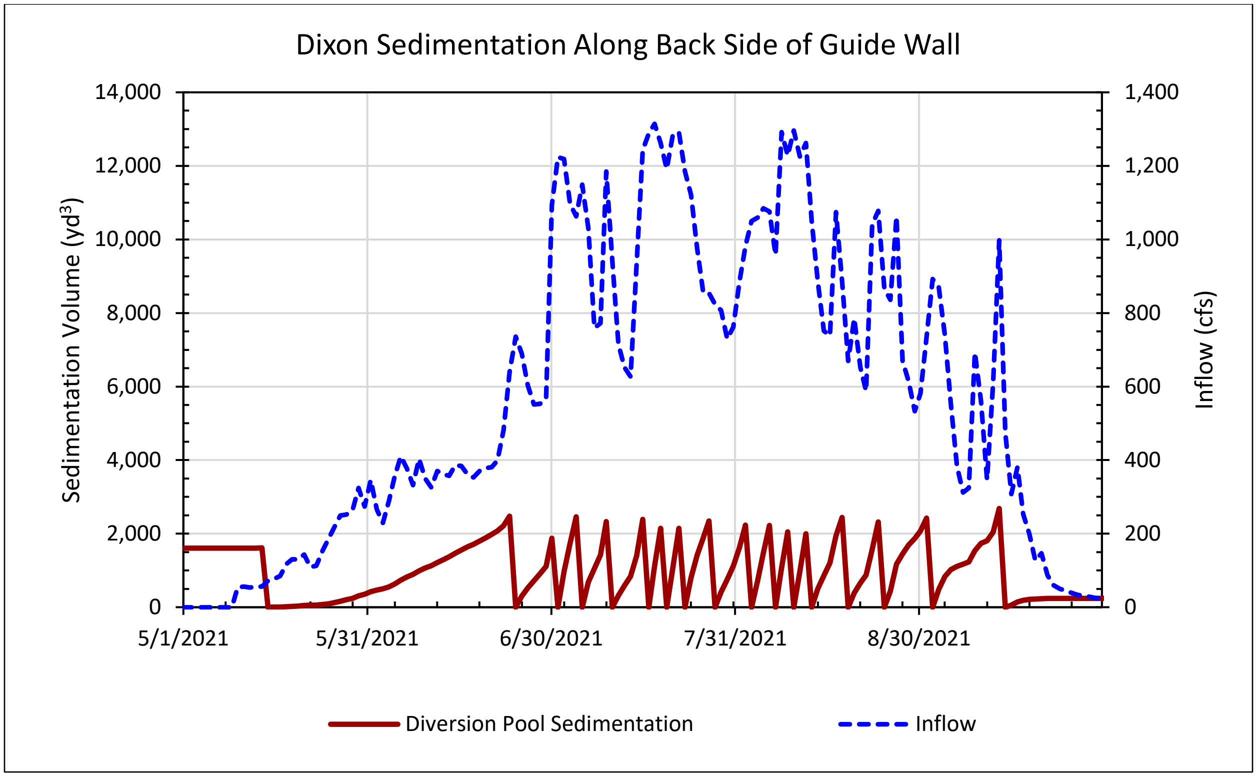



**Figure 17. Example application of mechanical sediment flushing criteria during 2021, where sedimentation is tracked daily.**

# 5.0 SETTLING BASIN MODEL RESULTS

Settling basin model results are presented for the frequency of hydraulic and mechanical sediment flushes from the Dixon Diversion pool. HEC-RAS model results are summarized for the time necessary to conduct hydraulic sediment flushes for a range of inflow discharges (Section 5.2).

## 5.1 FREQUENCY OF SEDIMENT FLUSHES

For each of the 1,000 model simulations, the number of hydraulic and mechanical sediment flushes were computed for each year of the 46-year hydrology record. Example results are provided for the case based on an assumed gravel and cobble load of 40,000 yd$^3$ per year (representing 5% of the total load) and a sediment-discharge exponent of 2 (Figure 18). For this example, the average number of hydraulic flushes of the front side area of the sediment guide wall is 20 per year, with a standard deviation of eight per year. The minimum number of hydraulic flushes is four per year, and the maximum number was 39 flushes per year. For the back side area, the average number of mechanical sediment flushes is 17 per year, with a standard deviation of 7. The minimum number of flushes is two per year, and the maximum number was 34 flushes per year.

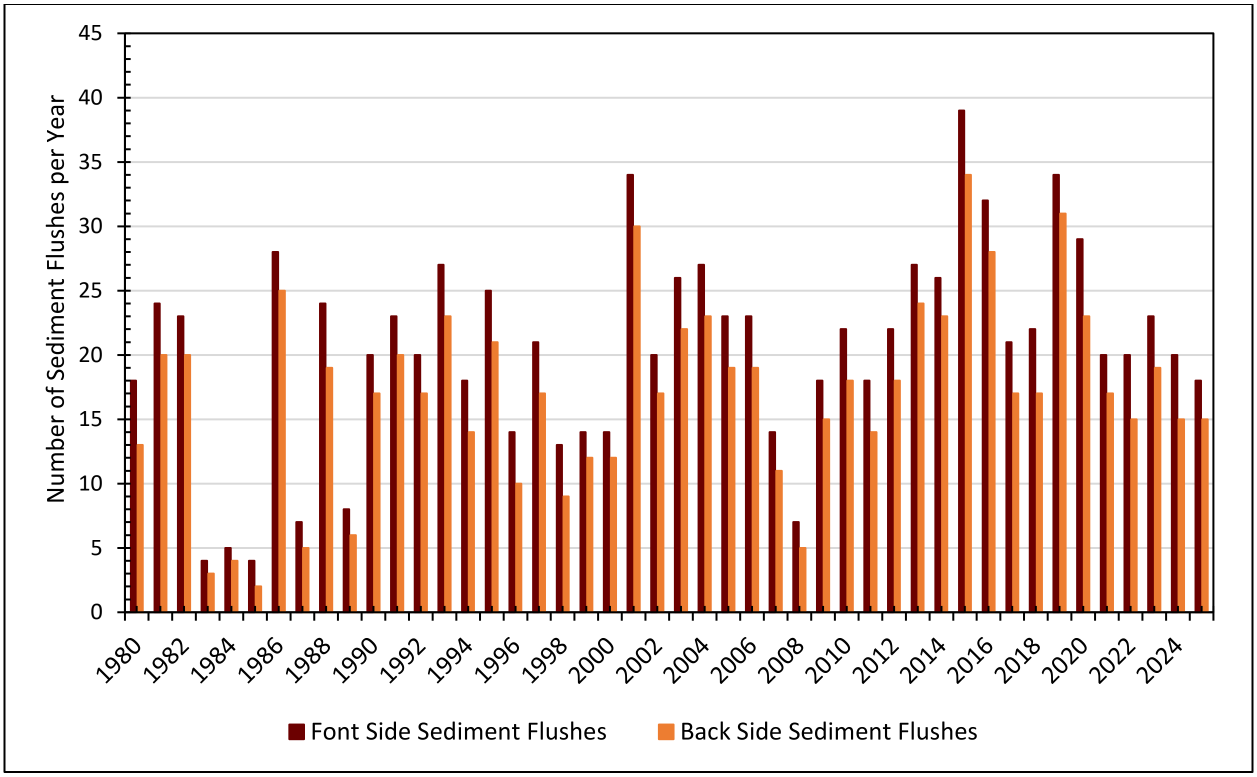



**Figure 18. Example sediment flushing results based on a gravel and cobble load of 40,000 yd$^3$ per year (representing 5% of the total load) and a sediment-discharge exponent of 2.**

The statistical distribution of the annual sediment flushes for the 1,000 simulations is presented in Figure 19. For these 1,000 different simulations, the number of front side sediment flushes ranged from 0 to 74 flushes per year, with a median of 14 sediment flushes per year. Simulations with more than 39 flushes are outliers. When the simulated years are ranked by the number of sediment flushes, the lower and upper quartiles (25% and 75%) of front side sediment flushes were 9 and 21 flushes per year, which accounts for one-half of all years simulated. Five percent of the years had no more than three font-side sediment flushes per year, and 95% of the years had no more than 32 flushes per year. The average discharge during a front side flushing event is ~1,200 cfs.

Mechanical flushing of the back side of the sediment guide wall area will take place during low flow conditions, or during a hydraulic flush of the front side area when the Obermeyer gates are lowered down to the channel bed elevation. The frequency of back side sediment flushes is expected to be very similar to the frequency of front side sediment flushes because the frequency of the hydraulic and mechanical sediment flushes are driven by the sediment inflow rates. For these 1,000 different simulations, the number of back side sediment flushes ranged from 1 to 75 flushes per year, with a median of 13 sediment flushes per year. Simulations with more than 38 flushes are outliers. The lower and upper quartiles (25% and 75% of the years) of back side sediment flushes are 8 and 20 flushes per year, which accounts for one-half of all years simulated. Five percent of the years had no more than two back side sediment flushes per year, and 95% of the years had no more than 32 flushes per year.

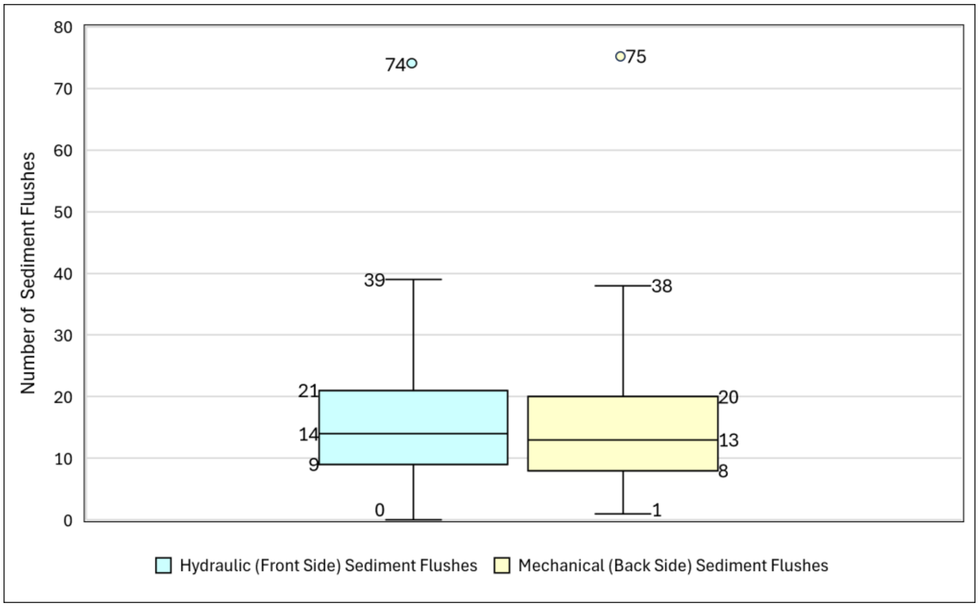



**Figure 19. Distribution of sediment flushes based on 46,000 simulation years.**

The Monte Carlo results show the wide range of sediment flushes per year, depending on hydrology and sediment yield rates from the Dixon Glacier (Figure 20). Based on the probability distribution of the results, the most frequent number of front side sediment guide wall flushes was between 10 and 15 flushes per year. There is considerable variability in the number of sediment flushes per year. Ninety percent of the simulated years had between 3 and 32 front side sediment flushes per year.

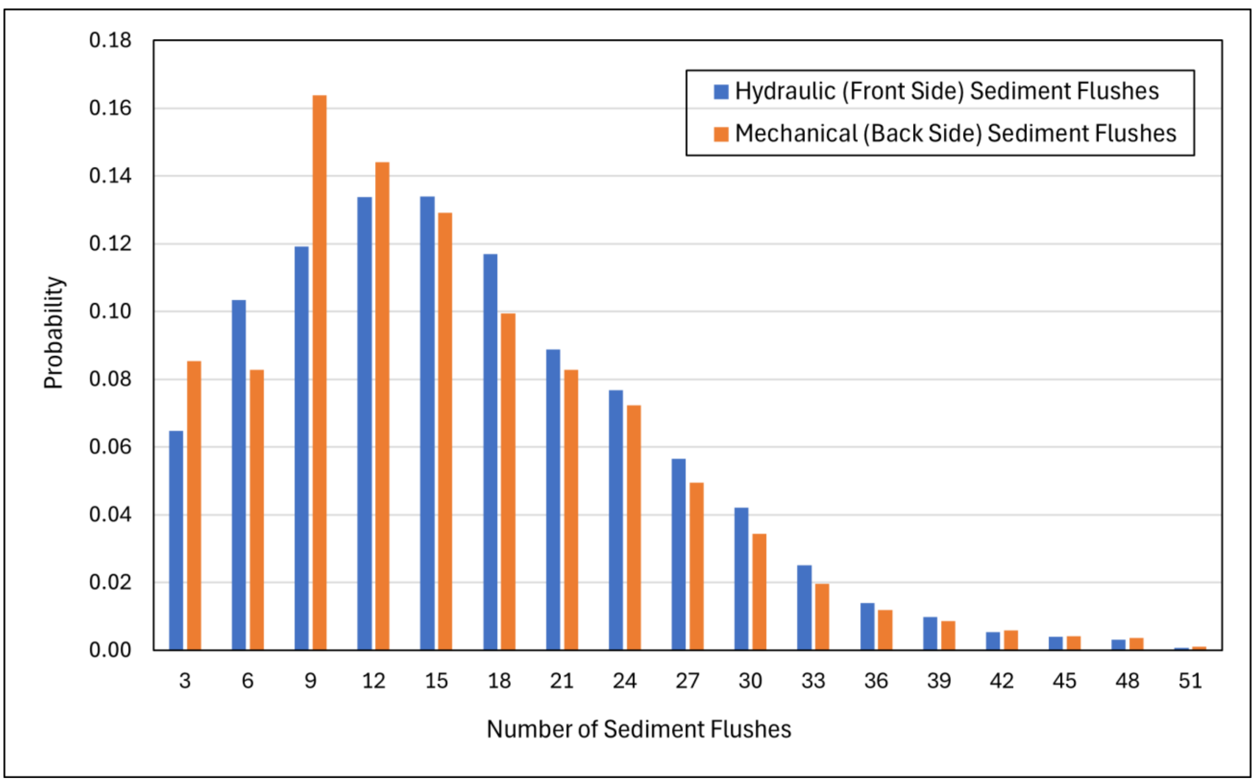



**Figure 20. Probability of sediment flushes based on 46,000 simulation years.**

The most frequent number of back side sediment flushes is 7 to 9 flushes per year. Ninety percent of the simulated years have between 2 and 32 back side sediment flushes per year.

## 5.2 DURATION OF HYDRAULIC SEDIMENT FLUSHES

The front side of the guide wall model area will be cleared of sediment hydraulically using the glacial runoff to remove sediment from the diversion pool. Hydraulic flushing will be performed by lowering the two 10-m wide Obermeyer gates (lowered to the channel bed elevation) to allow trapped sediment to be carried downstream to the EFMR. During a hydraulic sediment flush, no water will be diverted to Bradley Lake.

Intuitively, the time it will take to flush the sediment will depend on the inflow rate. Several quasi-steady HEC-RAS model iterations were run with flow rates of 500, 750, 1,000, 1,250, and 2,500 cfs. The hydraulic flushing modeling begins with a sediment delta (Figure 10) on the front side area composed of the deposited sediment (i.e., channel bottom) as predicted in the settling basin model. Each simulation was run until the sediment was completely flushed from the diversion pool. Using the Meyer-Peter and Muller equation, the time to flush completely will be about 24 hours at the average flushing flow rate of approximately 1,250 cfs. Note that the deposited sediment does not necessarily need to be completely flushed to restore operations; a partial flush may be desirable to restore operations when the inflow is relatively small (e.g., 500 cfs) and the time to completely flush the sediment is significantly longer. To restore operations at a lower inflow rate, a partial flush could be performed, and then operators could wait until a larger, more efficient inflow is available to completely flush the diversion pool. Appendix B presents the hydraulic sediment flushing model in more detail.

# 6.0 DISCUSSION

The sediment settling-basin model is a useful tool for simulating the diversion pool sedimentation by particle size range over decades of time. Results from these model simulations provide insights into the frequency sediment flushes may be needed to maintain water diversion operations at the Dixon Diversion Dam.

In the absence of sediment load measurements (suspended sediment concentration and bed load), model inputs were estimated as probability distributions for a reasonable range of values. Application of the Monte Carlo approach provided a method for evaluating the uncertainty in the sediment analysis by accounting for the uncertainty and expected ranges in the model inputs: average annual bed-material load, the portion of total load that is bed-material load, and the exponent of the sediment-discharge equation.

The average annual bed-material load from the Dixon Glacier was estimated from the bed-surface change measurement of the Martin River braid plain (40,000 $yd^3$ per year) [4]. Bed load measurements were not available to corroborate this estimate, so the uncertainty for the bed-material load was judged to range from 10,000 to 80,000 $yd^3$ per year.

Bed-material load was estimated to represent 5% of the total sediment load. No suspended sediment concentrations were available to compute the total load, so the uncertainty for this portion was judged to be as low as 3% and as high as 15%.

The daily sediment loads were assumed to vary with an exponent of the mean daily discharge. The exponent for the sediment-discharge equation was assumed to be 2. No sediment load measurements were available to verify this assumption, so the uncertainty for this exponent was judged to be as low as 1.5 and as high as 3. Sediment loads could also vary over time, for the same discharge, as channels within the glacier evolve, and when sub-glacial meltwater encounters pockets of till [11]. As developed, the model only allows the daily sediment loads to vary with an exponent of discharge. However, the computed daily sediment loads should represent the average load entering the Dixon diversion pool area for a given discharge.

The diversion pool behind Dixon Diversion Dam will act as a sediment-settling basin, trapping virtually all inflowing cobbles, gravel, and coarse sand particles. The finer the sediment particle size, the greater the probability that it will pass downstream to the EFMR or be diverted through the tunnel to Bradley Lake. Most of the sand-sized particles entering the diversion pool are expected to deposit, while most of the silt and clay-sized particles are expected to either pass downstream to the ERMR or through the diversion tunnel.

The sediment guide wall will steer the inflowing water and sediment load toward the diversion dam. The guide wall will create a longer flow path to the tunnel's forebay weir, which will allow more time for sediment particles to deposit. The sediment guide wall also constricts the inflow leading to the diversion dam, which facilitates hydraulic flushing of previously deposited sediment when the Obermeyer gates are lowered to the channel bed level.

Model simulations show significant year-to-year variations in the number of sediment flushes. For the base case (40,000 $yd^3$ per year average annual bed-material load, representing 5% of the total load, and a sediment discharge exponent of 2), the annual number of front side sediment flushes for the 46 years of hydrology varies from 4 to 39, with a median of 21. The average number of flushes is 20 with a standard deviation of 8. When all 1,000 simulations are considered (46,000 simulation years), the annual number of front side sediment flushes varies from 0 to 74, with a median of 14. The average annual number of flushes is 16, and the standard deviation is 9. Both the median and average number of sediment flushes decreases when considering all 1,000 simulations compared to the base case, primarily because the 10% coarse material ratio was as equally weighted as a 5% coarse material ratio. Monitoring sediment accumulation and conducting periodic flushes will be needed to appropriately manage the system; however the uncertainty in the actual sediment load and the variability in expected sediment parameters, will require the operators to implement an adaptive management program based on the inflow and observed conditions.

# 7.0 CONCLUSIONS

The diversion pool behind the Dixon Diversion Dam will trap a significant portion of the inflowing sediment. The pool will tend to trap the coarser sediment particles (cobble, gravel, and coarse sand), while finer sediment particles will tend to pass through the pool to either the downstream river channel or through the diversion tunnel.

The sediment guide wall is expected to steer inflowing sediment particles toward the diversion dam. The sediment guide wall also creates a longer flow path, giving sediment more settling time, before water is diverted through the tunnel to Bradley Lake.

Based on sediment settling basin model simulations, there will be significant variability in the annual and daily sediment loads entering the diversion pool. Higher sediment loads will fill the pool more rapidly than lower sediment loads. Once sediment has largely filled the channel along the front side of the guide wall, hydraulic flushing will be necessary to prevent coarse sediment particles from entering the diversion tunnel. Sedimentation along the back side of the guide wall will likely need to be mechanically flushed to maintain the trap efficiency for coarse particles. Sediment flushed to the downstream river channel will primarily consist of cobble, gravel, and coarse sand.

The annual number of sediment flushes will vary from year to year. Although the annual number of front side sediment (hydraulic) flushes could vary from 0 to 74, but the typical number of sediment flushes is expected to have range from 3 to 32 (90% of the years), with a median of 14 flushes per year. The number of back side (mechanical) flushes is similar to the front side. The annual number of back side sediment flushes could vary from 1 to 75, but the typical number of mechanical sediment flushes is expected to range from 2 to 32 (90% of the years), with a median of 13 flushes per year.

# 8.0 REFERENCES

[1] DOWL, "Bradley Lake Expansion Project - Martin River Hydrology Report," May 2026.

[2] Watershed GeoDynamics, "Amendment to Bradley Lake Hydroelectric Project (FERC No. 8221), Dixon Diversion Project, Geomorphology and Sediment Transport Study Report," Homer, AK, January 2025.

[3] B. Hallet, L. Hunter and J. Bogen, "Rates of erosion and sediment evacuation by glaciers: A review of field data and their implications," *Global and Planetary Change,* vol. 12, pp. 213-235, 1996.

[4] Watershed GeoDynamics, "Amendment to Bradley Lake Hydroelectric Project (FERC No. 8221), Bradley Lake Expansion Project - Martin River/Dixon Glacier Sediment Regime," May 2026.

[5] DOWL, "Bradley Expansion - Dixon Diversion Dam Hazard Potential Classification," July 2025.

[6] E. W. Lane, "Report of the Subcommittee on Sediment Terminology," *Transactions of the American Geophysical Union,* vol. 28, no. 6, pp. 936-938, 1946.

[7] D. Dehghan-Souraki, D. Lopez-Gomez, E. Blade-Castellet and A. Larese, "Optimizing sediment transport models by using Monte Carlo simulation and deep neural network (DNN): A case study of the Riba-Roja reservoir," *Environmental Modelling and Software,* vol. 175, 2024.

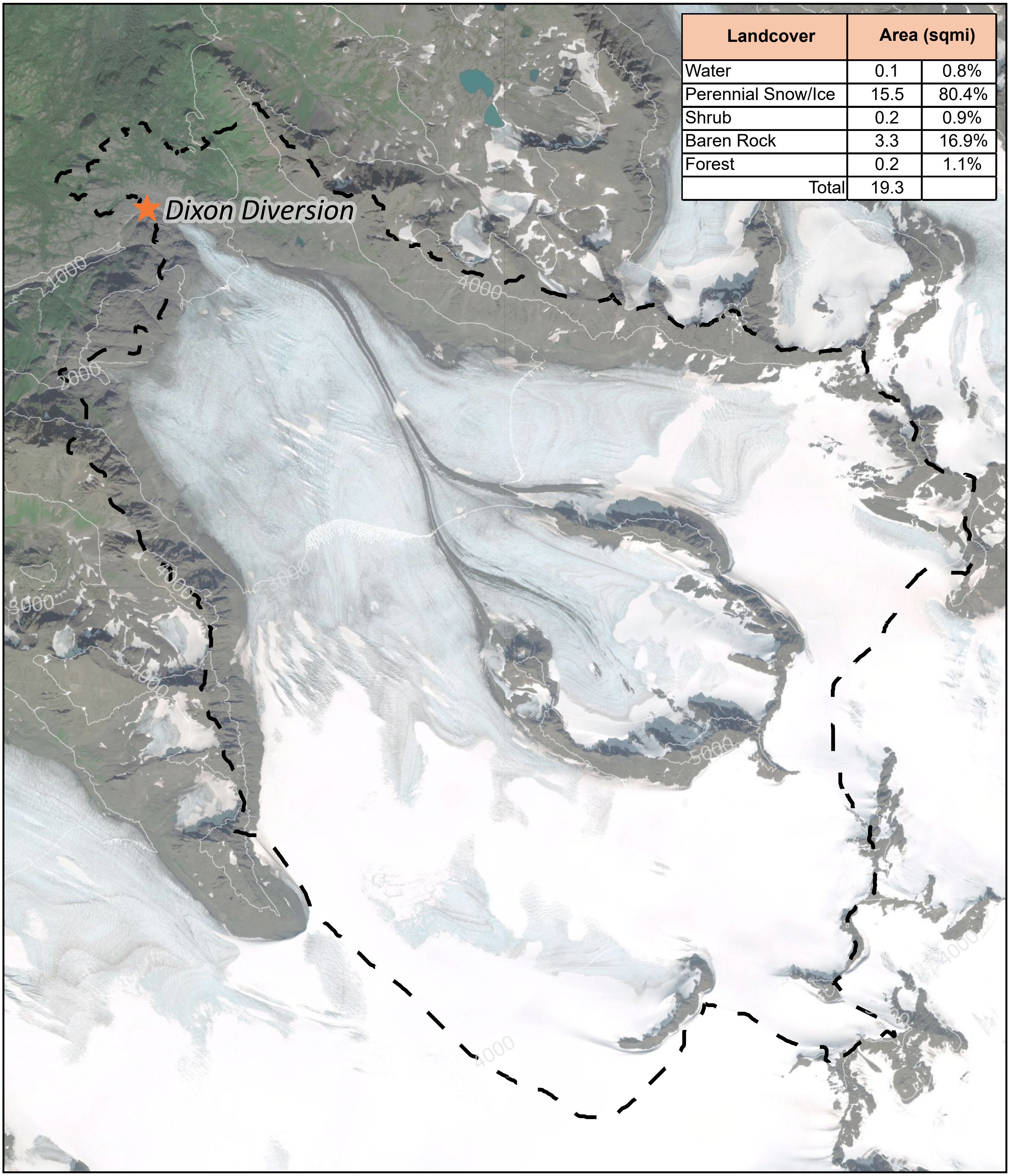
[8] E. L. Pemberton and J. M. Lara, "A Procedure to Determine Sediment Deposition in a Settling Basin," USBR, August 1971.

[9] W. W. Rubey, "Settling Velocities of Gravel, Sand, and Silt Particles," *American Journal of Science,* vol. 25, pp. 325-338, 1933.

[10] C. T. Yang, "Sediment Transport, Theory and Practice," The McGraw-Hill Companies, Inc., New York, NY, 1996.

[11] K. Dube, *Written Communication,* May 7, 2026.

# Appendix A: Watershed Overview




| Landcover | Area (sqmi) | |
|---|---|---|
| Water | 0.1 | 0.8% |
| Perennial Snow/Ice | 15.5 | 80.4% |
| Shrub | 0.2 | 0.9% |
| Baren Rock | 3.3 | 16.9% |
| Forest | 0.2 | 1.1% |
| Total | 19.3 | |

DOWL

0 1 2 Miles

N

## Dixon Glacier Basin Overview

# Appendix B: Sediment Transport Hydraulic Model

| | |
|---|---|
| TO: | Ryan T. McLaughlin; PE |
| FROM: | Mya Sawyer, EI; Andrew Johnson, PE; Timothy J. Randle, PHD, PE, BC.WRE |
| DATE: | 6/8/2026 |
| PROJECT: | Bradley Lake Expansion Project |
| SUBJECT: | Dixon Diversion Sediment Transport Hydraulic Model |

\\dowl.com\j\Projects\62\90200-01\32DxnDiversion\30pctDesign\Sediment\DixonSedTransportModel.docx

Sediment management and continuous maintenance at the Dixon Diversion are necessary for the longevity of the infrastructure and successful operations. Management activities include both hydraulic and mechanical sediment flushing. During a hydraulic flushing event, both 10 m (32.8 ft) Obermeyer gates will be lowered to allow sediment to flush downstream of the diversion to the Martin River. This memorandum documents the development and results of the sediment transport model for the Dixon Diversion.

# OTHER ANALYSIS

DOWL developed a settling basin model to estimate sedimentation rates in the diversion pool and the frequency of flushing events. The model distributes sediment inflow from a yearly average coarse material loading, and daily synthetic and measured hydrograph from 1980 to 2025. The most probable portion of coarse sediment to the total sediment load is 5%. The storage capacity of the diversion pool along the front side of the sediment guide wall is 11,000 yd$^3$, and the average settling length is 200 ft (used for sediment trapping efficiency). Additional sediment will be deposited along the back side of the sediment guide wall, and this sediment will be flushed using mechanized equipment (mechanical flushing). Sedimentation rates from the settling basin model were used to develop gradations for the one-dimensional (1D) model presented in this memorandum.

The volume of deposited coarse sediment (very fine sand to small cobbles) in the diversion pool was calculated for three assumed delta lengths and a normal pool elevation of ~1,273 ft. Sediment deposits in a delta configuration with an inflection point at the normal pool level. Upstream of the normal pool level, the delta topset extends at a slope of about one-half the base channel slope, and downstream of the normal pool level, the delta foreset extends downstream with a slope of about double the base channel slope. The three arbitrary sediment deltas are presented in Figure 1 (deltas 1, 2, and 3) have foreset lengths of 50 ft, 75 ft, and 170 ft, respectively. The corresponding incremental coarse delta volumes are shown below in Figure 1, with a constant channel width of 100 ft. A sand layer (very fine sand to very coarse sand) forms downstream of the sediment delta, extending to the diversion dam. Together, the coarse sediment delta and downstream sand volumes represent the total sediment storage capacity of approximately 11,000 yd$^3$.

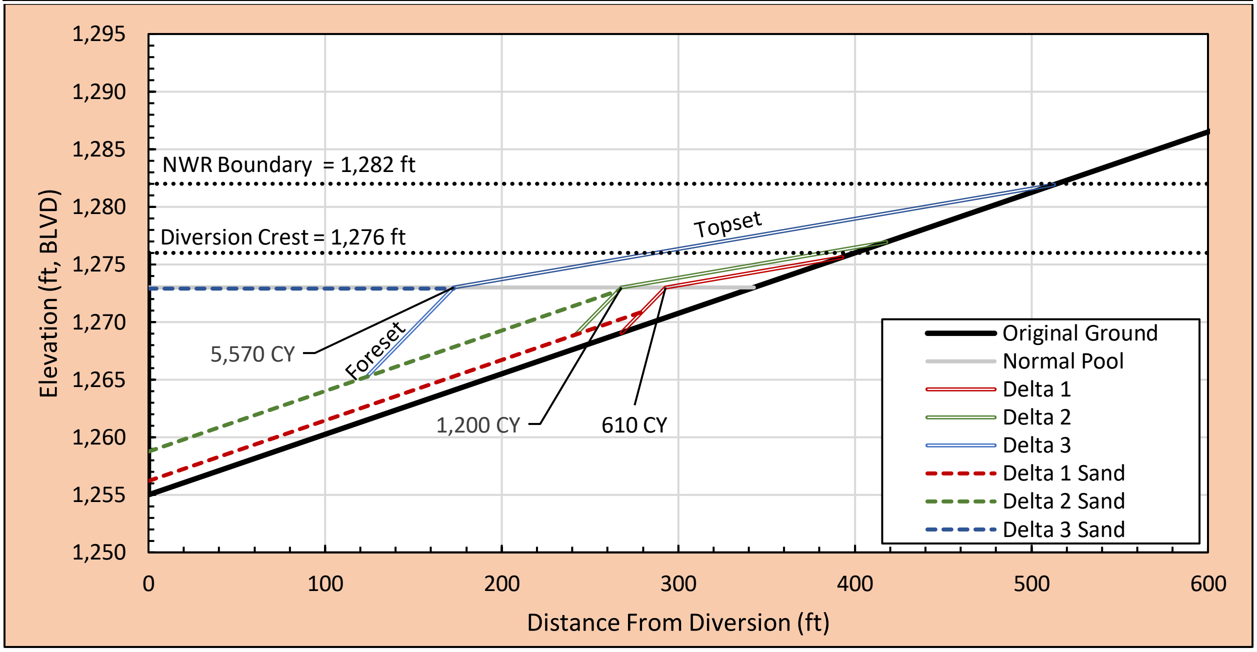



**Figure 1: Sediment Delta Volumes and Configurations**

# 1D HYDRAULIC MODEL

DOWL developed a one-dimensional (1D) hydraulic model using HEC-RAS version 6.6 to estimate the time required to hydraulically flush the deposited sediment in the diversion pool that is along the front side of the sediment guide wall. To simplify the hydraulic modeling, no sediment is included in the inflow. The model terrain was developed from light detection and ranging (LiDAR) collected in 2022 with 1-ft resolution. The projected coordinate system is State Plane Alaska Zone 4, and the vertical datum is the Bradley Lake vertical datum (BLVD), which is 9.76 US ft lower than the North American Vertical Datum of 1988 (NAVD88).

The model extends upstream and downstream of the diversion dam approximately 850 ft and 220 ft, respectively, to limit the potential for the boundary conditions to influence the area of interest. Cross-sections are spaced approximately at 40 ft; however, the spacing decreases to 10 ft along the sediment delta where the slopes are steeper. The accumulated sediment is modeled using a terrain modification based on the geometry of Delta 3 with a sand layer downstream (see Figure 1). The total sediment volume (delta and sand layer) is 11,000 $yd^3$, which matches the storage capacity in the settling basin model. The cross-sectional division between the channel and floodplains corresponds to where the 2-year peak water surface elevation intersects the channel boundary. The Manning's *n* roughness values are 0.09 for the channel and 0.05 for the overbanks. The high roughness value of 0.9 was selected for the channel to account for the energy dissipation caused by rapid erosion along the steep slope of the exposed delta surface.

## MODEL INPUTS

Quasi-unsteady (i.e., an unsteady model that allows for changing geometry with constant inflow) flow files were created for five discharge scenarios. The upstream boundary conditions were a constant discharge for all scenarios:

- 500 cfs
- 750 cfs

- 1,000 cfs
- 1,250 cfs (average discharge during a flush event as resulting from the settling basin model)
- 2,500 cfs (approximate 2-year flood)

Simulations are run up to 10 days with 5-minute computation increments. The normal depth was calculated as the downstream boundary condition, and the water temperature remains constant at 33 degrees Fahrenheit.

The initial bed-material represented the reservoir sediment deposits of sand, gravel, and cobble. Some clay and silt-sized particles are expected to deposit within the interstitial spaces of the larger gravel and cobble particles. However, the small amount of clay and silt will be readily eroded with the larger material and transported in suspension as wash load. Therefore, clay and silt-sized particles are excluded from the model simulations. The natural channel bed material is not included in the model because only accumulated sediment is flushed, assuming no erosion of the existing channel. The assumed sediment unit weight was 100 lb/yd$^3$. Both the coarse material and the sand gradations were developed from the settling basin model using a representative channel discharge of 1,000 cfs and a settling length of 200 ft, which is the average settling basin length as the growing sediment delta shortens the pool. Gradations are presented in Table 1 and Table 2.

**Table 1: Sand Layer Gradation**

| Sediment Particle Size Class | Sediment Particle Diameter Range (mm) | | Grain Class % |
|---|---|---|---|
| Very Fine Sand | 0.0625 | 0.125 | 11.9 |
| Fine Sand | 0.125 | 0.25 | 19.2 |
| Medium Sand | 0.25 | 0.5 | 24.8 |
| Coarse Sand | 0.5 | 1 | 21.5 |
| Very Coarse Sand | 1 | 2 | 22.6 |

**Table 2. Coarse Sediment Gradation**

| Sediment Particle Size Class | Sediment Particle Diameter Range (mm) | | Grain Class % |
|---|---|---|---|
| Very Fine Sand | 0.0625 | 0.125 | 9.8 |
| Fine Sand | 0.125 | 0.25 | 15.9 |
| Medium Sand | 0.25 | 0.5 | 20.5 |
| Coarse Sand | 0.5 | 1 | 17.8 |
| Very Coarse Sand | 1 | 2 | 18.7 |
| Very Fine Gravel | 2 | 4 | 3.1 |
| Fine Gravel | 4 | 8 | 3.1 |
| Medium Gravel | 8 | 16 | 3.1 |
| Coarse Gravel | 16 | 32 | 3.1 |
| Very Coarse Gravel | 32 | 64 | 3.1 |
| Small Cobbles | 64 | 128 | 1.7 |

The maximum erosion depth at each cross-section is the distance between the top of the sediment delta or sand layer and the existing channel bed elevation. The movable bed limits are placed at the bank stations, and the default veneer method was selected to change wetted nodes by the same vertical distance.

## MODEL RESULTS

The model simulations were run using the Meyer-Peter and Muller (MPM) transport function, and the default bed-material sorting and fall velocity computational methods. The MPM equation is appropriate for gravel-sized sediment but was not developed for sand-sized sediment [1]. The other available equations in HEC-RAS are either unsuitable for gravel-bed channels or did not produce reasonable flushing durations and longitudinal reservoir profile plots. This is likely due to the mixed sand and gravel bed-material size gradation of the deposited reservoir sediment. Figure 2 shows the flushed reservoir-sediment volume versus time for a range of river discharges using the MPM equation.

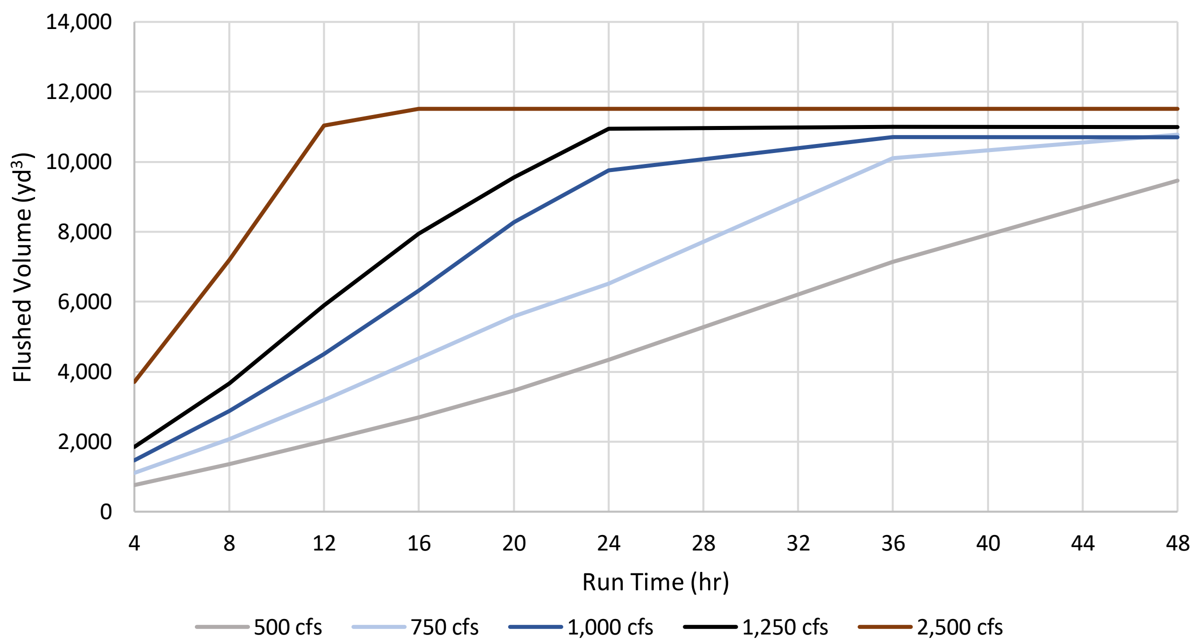



**Figure 2: MPM HEC-RAS Flush Duration**

Based on the HEC-RAS model results, the reservoir sediment is completely flushed after approximately 24 hours during a typical flushing event (1,250 cfs). For a simulated discharge of 1,250 cfs, the longitudinal reservoir profile plots are presented in Attachment 1 for the initial conditions, after 12 hours, and after 24 hours. With an inflow discharge of 500 cfs, the duration exceeds 3 days to completely flush the reservoir sediment. Therefore, to maximize diverted runoff during low flows (e.g., 500 cfs), only enough sediment should be flushed from the reservoir to achieve operable conditions, and the pool should be flushed again later when the flow increases and flushes will be more efficient.

## SRH-CAPACITY COMPARISON

The MPM equation is the only available option for gravel-sized sediment in HEC-RAS that produces reasonable results. To evaluate how different equation sets compare to the MPM, DOWL used SRH-Capacity version 2.0 (SRH). The US Bureau of Reclamation (Reclamation) developed the SRH 1D hydraulic model to calculate at-a-station sediment transport capacity in a river reach, given hydraulics from a HEC-RAS cross-section.

The following appropriate equations were selected in the SRH model for comparison:

- Meyer-Peter and Muller's method [1]
- Yang's 1973 sand and 1984 gravel formulas [2] [3]
- Parker's (1990) method using Einstein's method to correct shear stress [4]
- Wilcock and Crowe's (2003) method using Einstein's method to correct shear stress [5]

Initially, the HEC-RAS cross-section selected to represent the hydraulic conditions of the diversion pool flush was on the steep downstream slope of the delta. However, the SRH-Capacity model produced unexpected results where computed sediment transport capacities were the same very large value, for a given discharge, regardless of the selected transport formula. Different sediment transport formulas normally produce different sediment transport capacities, but the very steep slopes of the eroding delta front (friction slopes between 7.5% and 9.2%) likely produced maximum limits to the transport capacity computations. Therefore, both the friction and channel bed slopes were set equal to 0.5%, which is more typical of a natural gravel-bed river and more consistent with the slopes used to develop the gravel transport formulas. The coarse sediment size gradation (Table 2) was used in the SRH-Capacity model. Since the friction and channel slopes used by the SRH-Capacity model are not nearly as steep as the slope of the eroding reservoir delta, the results can only be used to show the relative differences in the transport rates of the different equation sets. The computed sediment transport capacity rates for the initial erosion of the exposed reservoir sediment were applied to the entire sedimentation volume as a first approximation of the sediment flushing duration.

The MPM flushing durations from HEC-RAS were compared to the MPM flushing durations approximated using results from the SRH-Capacity model. The ratio of these MPM results was then applied to the other flushing durations approximated using other transport formulas available in the SRH-Capacity model. The application of the ratio provided a way to estimate potential flush durations if those equations were modeled in HEC-RAS. Table 3 lists the estimated flushing durations. See Attachment 3 for the scaling computations.

**Table 3: Flushing Duration Comparison**

| Equation | Model | 500 cfs | 750 cfs | 1,000 cfs | 1,250 cfs | 2,500 cfs |
|---|---|---|---|---|---|---|
| **Actual HEC-RAS Flush Time (hr)** | | | | | | |
| MPM | HEC-RAS | 78 | 42 | 29 | 25 | 14 |
| **Estimated HEC-RAS Flush Time (hr)** | | | | | | |
| MPM | SRH | 78 | 42 | 29 | 25 | 14 |
| Yang | SRH | 21 | 11 | 6 | 6 | 2 |
| Parker | SRH | 9 | 64 | 42 | 50 | 25 |
| Wilcock & Crowe | SRH | 475 | 308 | 184 | 220 | 90 |

The available transport equations are highly sensitive to gradation, none of which apply to the wide range of sediment sizes observed at the East Fork Martin River. The Wilcock & Crowe equation unreasonably overestimates flushing durations compared to MPM. With the high uncertainty of the results, a 1,250 cfs flush could have a duration of 6 to 50 hours. The HEC-RAS model with the MPM equation may be the best estimate with a of flush time of approximately 24 hours (1 day). Close monitoring of flushing durations after the diversion is built will be critical for more refined flushing duration estimates.

# REFERENCES

[1] E. Meyer-Peter and R. Müller, "Formulas for Bed-Load Transport," 1948.

[2] C. T. Yang, "Incipient Motion and Sediment Transport," *Journal of the Hydraulics Division,* vol. 99, no. 10, pp. 1679-1704, 1973.

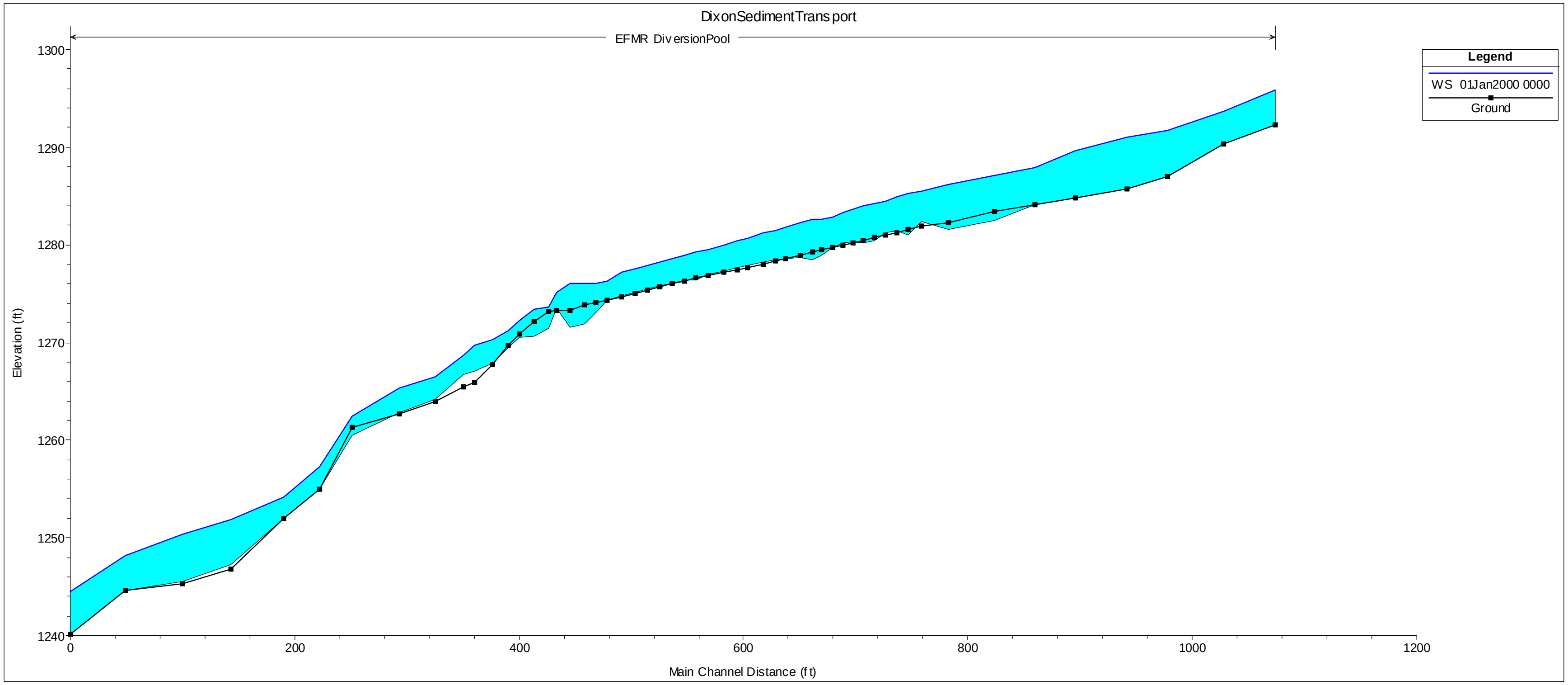
[3] C. T. Yang, "Unit Stream Power Equation for Gravel," *Journal of Hydraulic Engineering,* vol. 110, no. 12, pp. 1793-1797, 1984.

[4] G. Parker, "Surface-Based Bedload Transport Relation for Gravel Rivers," *Journal of Hydraulic Research,* vol. 28, no. 4, pp. 417-436, 1990.

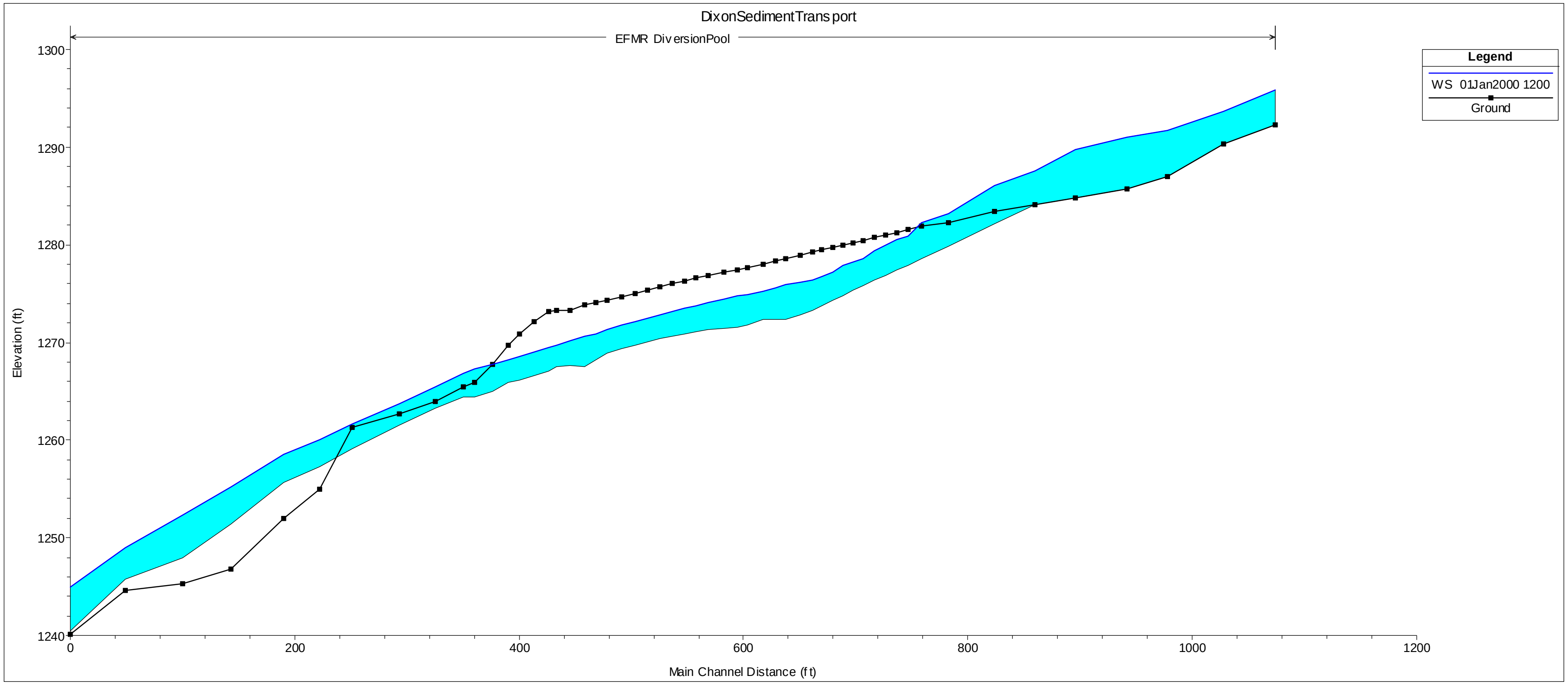
[5] P. R. Wilcock and J. C. Crowe, "A Surface-Based Transport Model for Sand and Gravel," *Hydraulic Engineering,* vol. 129, no. 2, pp. 120-128, 2003.

# Attachment 1: HEC-RAS Profile Plots

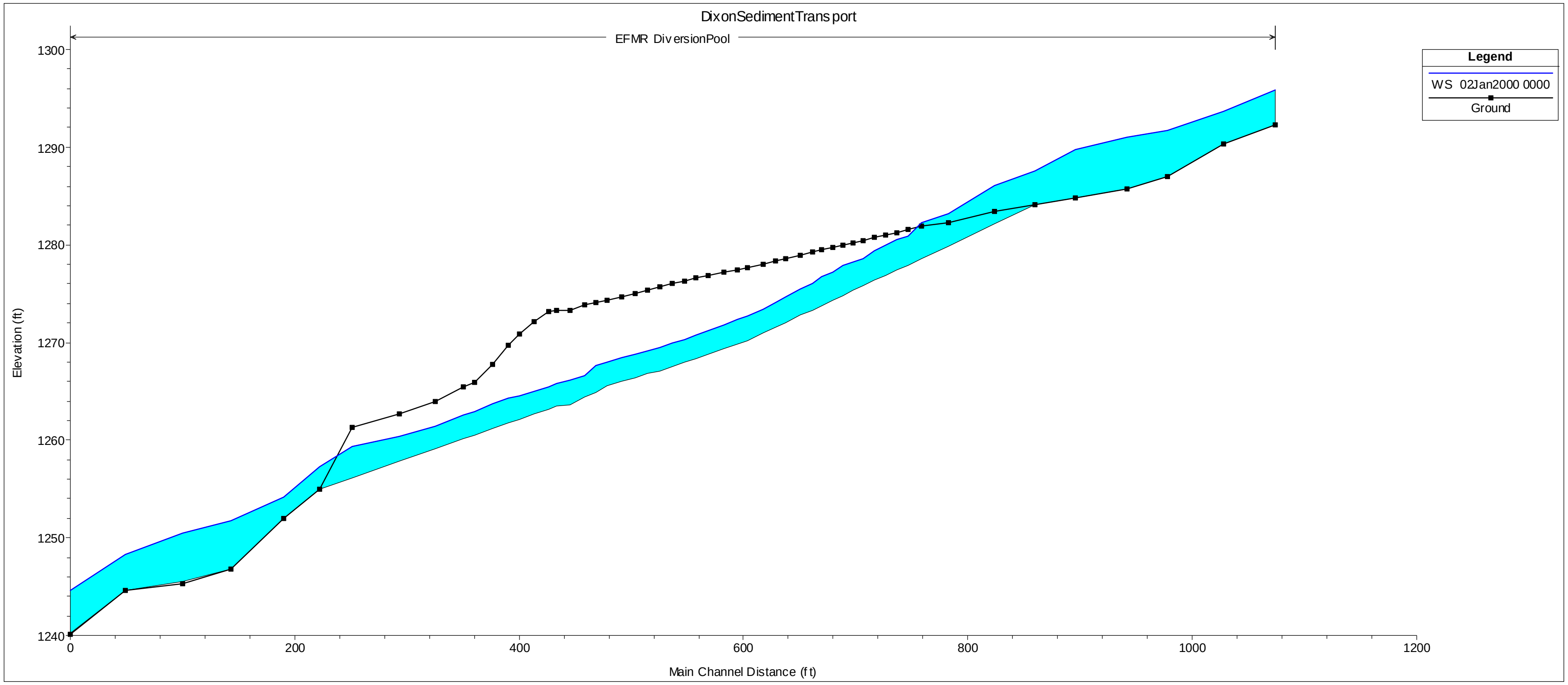
# 1,250 cfs Profile Plot at Initial Timestep



# 1,250 cfs Profile Plot After 12 Hours



# 1,250 cfs Profile Plot After 24 Hours



# Attachment 2: SRH Output

#QsPotential(i)=sediment transport capacity for size I if all bed material are in size i
#QsCapTotal=Total sediment transport capacity
#QsCapacity(i)=sediment transport capacity for size i
#Unit: English
number of size fractions = 11
sediment size

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| d | low | = | 0.0625 | d | high | = | 0.125 |
| d | low | = | 0.125 | d | high | = | 0.25 |
| d | low | = | 0.25 | d | high | = | 0.5 |
| d | low | = | 0.5 | d | high | = | 1 |
| d | low | = | 1 | d | high | = | 2 |
| d | low | = | 2 | d | high | = | 4 |
| d | low | = | 4 | d | high | = | 8 |
| d | low | = | 8 | d | high | = | 16 |
| d | low | = | 16 | d | high | = | 32 |
| d | low | = | 32 | d | high | = | 64 |
| d | low | = | 64 | d | high | = | 128 |

bed material

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Bed | Material | 1 | 0.0979 | 0.1588 | 0.2052 | 0.1775 | 0.1869 | 0.0313 | 0.0313 | 0.0313 | 0.0313 | 0.0313 | 0.0174 |

| bed | material | xx16(mm) | xx50(mm) | xx65(mm) | xx84(mm) | xx90(mm) | xx100(mm) |
|---|---|---|---|---|---|---|---|
| Bed | Material | 1 | 0.1639 | 0.5803 | 1.0403 | 2.7154 | 10.2627 | 90.5097 |

-----------------------------------------------------------------------

Input flow data

| run# | description | flow_tot | flow_chan | velocity | topWidth | hyd. Rad | fSlope | slope | temperature | local_coef1 | local_coef2 | RiverReach |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | cfs | cfs | ft/s | ft | ft | ft/ft | ft/ft | F | - | - | - |
| 1 | 500 | 500 | 500 | 4.2 | 106.41 | 1.1 | 0.005 | 0.005 | 34 | 0 | 0 | 1 |
| 2 | 750 | 750 | 750 | 4.62 | 106.6 | 1.49 | 0.005 | 0.005 | 34 | 0 | 0 | 1 |
| 3 | 1000 | 1000 | 1000 | 5.25 | 106.7 | 1.74 | 0.005 | 0.005 | 34 | 0 | 0 | 1 |
| 4 | 1250 | 1250 | 1250 | 5.26 | 106.87 | 2.15 | 0.005 | 0.005 | 34 | 0 | 0 | 1 |
| 5 | 2500 | 2500 | 2500 | 7.13 | 107.25 | 3.12 | 0.005 | 0.005 | 34 | 0 | 0 | 1 |

*********************************************************************

sediment transport formula = YANG73
Case 1 coef1= 0 coef2= 0

-----------------------------------------------------------------------

| ii | description | QsD50Pot | QsPotTol | QsPotential01 | QsPotential02 | QsPotential03 | QsPotential04 | QsPotentia | QsPotential06 | QsPotential07 | QsPotential08 | QsPotential09 | QsPotential10 | QsPotential11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/da | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day |
| 1 | 500 | 6225.1273 | 236214.0209 | 181235.4661 | 33812.9848 | 10590.4084 | 5255.9765 | 3538.735 | 621.5616 | 689.4391 | 469.4493 | 0 | 0 | 0 |
| 2 | 750 | 10410.3275 | 384553.8657 | 294428.3392 | 55520.1863 | 17581.8945 | 8818.7577 | 5985.022 | 662.4953 | 817.0033 | 710.4394 | 29.7276 | 0 | 0 |
| 3 | 1000 | 16147.7511 | 603820.9081 | 462731.2236 | 86698.3311 | 27334.346 | 13673.573 | 9281.223 | 934.64 | 1267.9792 | 1335.2652 | 564.3268 | 0 | 0 |
| 4 | 1250 | 19954.1544 | 719404.3202 | 549418.4632 | 104651.6228 | 33482.4053 | 16947.991 | 11597.82 | 741.4563 | 1014.7705 | 1079.3204 | 470.4756 | 0 | 0 |
| 5 | 2500 | 55640.0451 | 2079183.72 | 1595231.304 | 298712.8535 | 94230.1424 | 47006.2097 | 32042.5 | 1521.9477 | 2376.3722 | 3141.57 | 3611.2859 | 1309.5317 | 0 |

*********************************************************************

sediment transport formula = MEYER
Case 2 coef1= 0 coef2= 0

-----------------------------------------------------------------------

| ii | description | QsD50Pot | QsPotTol | QsPotential01 | QsPotential02 | QsPotential03 | QsPotential04 | QsPotentia | QsPotential06 | QsPotential07 | QsPotential08 | QsPotential09 | QsPotential10 | QsPotential11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/da | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day |
| 1 | 500 | 8079.8452 | 54998.1056 | 8380.5314 | 8326.2362 | 8217.9992 | 8002.9467 | 7578.587 | 6753.3484 | 5201.2673 | 2537.1894 | 0 | 0 | 0 |
| 2 | 750 | 12906.5254 | 92625.1011 | 13257.8635 | 13194.5053 | 13068.0929 | 12816.4883 | 12318.2 | 11341.5974 | 9471.0041 | 6085.7965 | 1071.5559 | 0 | 0 |
| 3 | 1000 | 16377.6953 | 120985.5736 | 16758.0543 | 16689.4991 | 16552.6699 | 16280.1407 | 15739.63 | 14677.0257 | 12627.5955 | 8851.0389 | 2809.922 | 0 | 0 |
| 4 | 1250 | 22648.236 | 173313.7317 | 23072.133 | 22995.7765 | 22843.3167 | 22539.4132 | 21935.69 | 20744.7653 | 18430.4545 | 14085.2217 | 6666.9591 | 0 | 0 |
| 5 | 2500 | 40005.0929 | 325784.8347 | 40518.2222 | 40425.8652 | 40241.3622 | 39873.2012 | 39140.27 | 37688.0811 | 34839.193 | 29370.4516 | 19415.838 | 4272.3485 | 0 |

*********************************************************************

sediment transport formula = PARKER
Case 3 coef1= 0.04 coef2= 0.9

-----------------------------------------------------------------------

| ii | description | QsD50Pot | QsPotTol | QsPotential01 | QsPotential02 | QsPotential03 | QsPotential04 | QsPotentia | QsPotential06 | QsPotential07 | QsPotential08 | QsPotential09 | QsPotential10 | QsPotential11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/da | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day |
| 1 | 500 | 6047.9725 | 64774.2528 | 6189.9689 | 6140.4572 | 6087.7344 | 6031.6192 | 5971.924 | 5908.4552 | 5841.015 | 5769.4007 | 5693.4065 | 5612.8247 | 5527.4471 |
| 2 | 750 | 7557.1414 | 81216.0486 | 7711.2584 | 7657.5615 | 7600.3339 | 7539.3688 | 7474.451 | 7405.3574 | 7331.8574 | 7253.7132 | 7170.6811 | 7082.5122 | 6988.9537 |
| 3 | 1000 | 10165.4616 | 109679.7857 | 10336.9657 | 10277.2631 | 10213.5736 | 10145.6542 | 10073.25 | 9996.0969 | 9913.9169 | 9826.423 | 9733.3173 | 9634.2925 | 9529.032 |
| 4 | 1250 | 10226.4626 | 110343.8662 | 10398.5089 | 10338.6183 | 10274.7273 | 10206.5921 | 10133.96 | 10056.5562 | 9974.1112 | 9886.3333 | 9792.9237 | 9693.5734 | 9587.9645 |
| 5 | 2500 | 20707.0563 | 224991.3833 | 20928.1125 | 20851.2793 | 20769.1754 | 20681.4579 | 20587.76 | 20487.714 | 20380.9024 | 20266.9059 | 20145.2788 | 20015.5532 | 19877.239 |

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sediment transport formula = WILCOCK
Case 4 coef1= 0.021 coef2= 0.33

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| ii | description | QsD50Pot | QsPotTol | QsPotential01 | QsPotential02 | QsPotential03 | QsPotential04 | QsPotentia | QsPotential06 | QsPotential07 | QsPotential08 | QsPotential09 | QsPotential10 | QsPotential11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/da | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day |
| 1 | 500 | 750.5356 | 8386.9495 | 1512.0092 | 1463.3936 | 1410.3428 | 1332.506 | 1155.416 | 781.7982 | 440.1544 | 212.2491 | 69.2394 | 9.522 | 0.319 |
| 2 | 750 | 1059.3695 | 11441.2411 | 2004.8315 | 1945.663 | 1880.9503 | 1785.7115 | 1567.604 | 1099.2113 | 655.685 | 343.7303 | 130.7608 | 25.8976 | 1.1955 |
| 3 | 1000 | 1653.7474 | 17229.6503 | 2906.4218 | 2829.8877 | 2745.9545 | 2621.9742 | 2335.812 | 1708.1703 | 1089.0949 | 626.6304 | 280.3388 | 78.2696 | 7.096 |
| 4 | 1250 | 1667.1865 | 17361.6954 | 2927.0357 | 2850.0891 | 2765.7003 | 2641.0406 | 2353.279 | 1721.944 | 1098.8759 | 633.0482 | 283.8092 | 79.5744 | 7.299 |
| 5 | 2500 | 4546.5719 | 45048.238 | 6940.5927 | 6801.0183 | 6647.1395 | 6418.215 | 5881.764 | 4656.677 | 3352.7403 | 2267.703 | 1317.4103 | 595.3661 | 169.6114 |

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sediment transport formula = YANG73
Case 1 coef1= 0 coef2= 0

| ii | description | QsCapTol | QsCapacity01 | QsCapacity02 | QsCapacity03 | QsCapacity04 | QsCapacity05 | QsCapacit | QsCapacity07 | QsCapacity08 | QsCapacity09 | QsCapacity10 | QsCapacity11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/da | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day |
| 1 | 500 | 26931.7367 | 17739.3274 | 5369.8401 | 2172.7282 | 932.9358 | 661.2126 | 19.4424 | 21.5657 | 14.6844 | 0 | 0 | 0 |
| 2 | 750 | 43995.9702 | 28818.6458 | 8817.1608 | 3607.1015 | 1565.3295 | 1118.3014 | 20.7229 | 25.5559 | 22.2225 | 0.9299 | 0 | 0 |
| 3 | 1000 | 68958.1815 | 45292.1322 | 13768.562 | 5607.9144 | 2427.0592 | 1734.1966 | 29.2355 | 39.6624 | 41.7671 | 17.6521 | 0 | 0 |
| 4 | 1250 | 82544.7862 | 53777.0792 | 16619.7242 | 6869.2503 | 3008.2684 | 2167.0517 | 23.1928 | 31.742 | 33.7611 | 14.7165 | 0 | 0 |
| 5 | 2500 | 237616.9591 | 156141.24 | 47438.5883 | 19332.256 | 8343.6022 | 5987.1417 | 47.6065 | 74.3329 | 98.2683 | 112.961 | 40.9622 | 0 |

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sediment transport formula = MEYER
Case 2 coef1= 0 coef2= 0

| ii | description | QsCapTol | QsCapacity01 | QsCapacity02 | QsCapacity03 | QsCapacity04 | QsCapacity05 | QsCapacit | QsCapacity07 | QsCapacity08 | QsCapacity09 | QsCapacity10 | QsCapacity11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/da | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day |
| 1 | 500 | 7118.4664 | 820.2864 | 1322.2896 | 1686.0047 | 1420.523 | 1416.059 | 211.2447 | 162.6956 | 79.3633 | 0 | 0 | 0 |
| 2 | 750 | 11525.631 | 1297.6797 | 2095.4194 | 2681.0499 | 2274.9267 | 2301.6552 | 354.7652 | 296.253 | 190.3637 | 33.5183 | 0 | 0 |
| 3 | 1000 | 14736.2013 | 1640.2784 | 2650.4593 | 3395.9458 | 2889.725 | 2940.9494 | 459.0974 | 394.9912 | 276.8605 | 87.8944 | 0 | 0 |
| 4 | 1250 | 20570.7534 | 2258.3004 | 3651.9593 | 4686.5349 | 4000.7458 | 4098.684 | 648.8963 | 576.5046 | 440.5857 | 208.5425 | 0 | 0 |
| 5 | 2500 | 36961.0534 | 3965.9236 | 6420.0317 | 8255.9179 | 7077.4932 | 7313.3598 | 1178.883 | 1089.77 | 918.7077 | 607.3274 | 133.6391 | 0 |

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sediment transport formula = PARKER
Case 3 coef1= 0.04 coef2= 0.9

| ii | description | QsCapTol | QsCapacity01 | QsCapacity02 | QsCapacity03 | QsCapacity04 | QsCapacity05 | QsCapacit | QsCapacity07 | QsCapacity08 | QsCapacity09 | QsCapacity10 | QsCapacity11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/da | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day |
| 1 | 500 | 6014.1824 | 605.8742 | 975.166 | 1248.9596 | 1070.6124 | 1115.854 | 184.8165 | 182.707 | 180.4669 | 178.0898 | 175.5692 | 96.067 |
| 2 | 750 | 7520.1831 | 754.778 | 1216.0973 | 1559.2845 | 1338.238 | 1396.6012 | 231.6396 | 229.3405 | 226.8961 | 224.2989 | 221.541 | 121.468 |
| 3 | 1000 | 10123.9607 | 1011.7822 | 1632.1322 | 2095.4168 | 1800.8536 | 1882.1868 | 312.6779 | 310.1073 | 307.3705 | 304.4582 | 301.3607 | 165.6146 |
| 4 | 1250 | 10184.8253 | 1017.806 | 1641.876 | 2107.9631 | 1811.6701 | 1893.5299 | 314.5691 | 311.9902 | 309.2445 | 306.3227 | 303.215 | 166.6388 |
| 5 | 2500 | 20652.6384 | 2048.4437 | 3311.3917 | 4261.004 | 3670.9588 | 3846.8239 | 640.8557 | 637.5146 | 633.9488 | 630.1443 | 626.0865 | 345.4664 |

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sediment transport formula = WILCOCK
Case 4 coef1= 0.021 coef2= 0.33

| ii | description | QsCapTol | QsCapacity01 | QsCapacity02 | QsCapacity03 | QsCapacity04 | QsCapacity05 | QsCapacit | QsCapacity07 | QsCapacity08 | QsCapacity09 | QsCapacity10 | QsCapacity11 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - | - | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/da | EngTons/day | EngTons/day | EngTons/day | EngTons/day | EngTons/day |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 500 | 1169.4832 | 147.9955 | 232.4015 | 289.3459 | 236.5198 | 215.8894 | 24.4546 | 13.768 | 6.6392 | 2.1658 | 0.2978 | 0.0055 |
| | 2 | 750 | 1571.5561 | 196.2329 | 308.9907 | 385.8958 | 316.9638 | 292.9068 | 34.3833 | 20.5098 | 10.7519 | 4.0902 | 0.8101 | 0.0208 |
| | 3 | 1000 | 2317.542 | 284.4806 | 449.4145 | 563.36 | 465.4004 | 436.4465 | 53.4316 | 34.0669 | 19.601 | 8.769 | 2.4483 | 0.1233 |
| | 4 | 1250 | 2334.5574 | 286.4983 | 452.6226 | 567.4111 | 468.7847 | 439.7102 | 53.8624 | 34.3728 | 19.8017 | 8.8776 | 2.4891 | 0.1269 |
| | 5 | 2500 | 5745.6307 | 679.3452 | 1080.0697 | 1363.7271 | 1139.2332 | 1099.0077 | 145.6609 | 104.8737 | 70.9338 | 41.2086 | 18.6231 | 2.9478 |

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| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sediment | transport | formula | = | YANG73 | | | | | | | | | |
| Case | 1 | coef1= | 0 | coef2= | 0 | | | | | | | | |
| reach | QiD50 | Qi01 | Qi02 | Qi03 | Qi04 | Qi05 | Qi06 | Qi07 | Qi08 | Qi09 | Qi10 | Qi11 | |
| | - | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs |
| | 1 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 528.3365 | 1259.8051 | 99999 |

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| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sediment | transport | formula | = | MEYER | | | | | | | | | |
| Case | 2 | coef1= | 0 | coef2= | 0 | | | | | | | | |
| reach | QiD50 | Qi01 | Qi02 | Qi03 | Qi04 | Qi05 | Qi06 | Qi07 | Qi08 | Qi09 | Qi10 | Qi11 | |
| | - | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs |
| | 1 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500.7861 | 1253.0054 | 99999 |

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| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sediment | transport | formula | = | PARKER | | | | | | | | | |
| Case | 3 | coef1= | 0.04 | coef2= | 0.9 | | | | | | | | |
| reach | QiD50 | Qi01 | Qi02 | Qi03 | Qi04 | Qi05 | Qi06 | Qi07 | Qi08 | Qi09 | Qi10 | Qi11 | |
| | - | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs |
| | 1 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 1133.752 | 999999 |

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| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| sediment | transport | formula | = | WILCOCK | | | | | | | | | |
| Case | 4 | coef1= | 0.021 | coef2= | 0.33 | | | | | | | | |
| reach | QiD50 | Qi01 | Qi02 | Qi03 | Qi04 | Qi05 | Qi06 | Qi07 | Qi08 | Qi09 | Qi10 | Qi11 | |
| | - | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs | cfs |
| | 1 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 500 | 1193.4884 |

# Attachment 3: SRH Flush Duration Calculations

| Equation | 500 cfs | 750 cfs | 1,000 cfs | 1,250 cfs | 2,500 cfs |
|---|---|---|---|---|---|
| HEC-RAS Flushing Rate (tons/day) | | | | | |
| Meyer Peter Muller | 5,861 | 8,791 | 13,169 | 14,770 | 15,545 |
| | HEC-RAS Flush Time (hr) | | | | |
| | 78 | 42 | 29 | 25 | 14 |
| SRH-Capacity Flushing Rate (tons/day) | | | | | |
| Meyer Peter Muller | 7,118 | 11,526 | 14,736 | 20,571 | 36,961 |
| Yang | 26,932 | 43,996 | 68,958 | 82,545 | 237,617 |
| Parker | 6,014 | 7,520 | 10,124 | 10,185 | 20,653 |
| Wilcock & Crowe | 1,169 | 1,572 | 2,318 | 2,335 | 5,746 |

500 cfs

| SRH Equation | Flushed Mass ($yd^3$/hr) | Flush Time (hr) | Ratio to RAS | HEC-RAS Flush Estimate (hr) |
|---|---|---|---|---|
| Meyer Peter Muller | 220 | 27 | 2.92 | 78 |
| Yang | 831 | 7 | | 21 |
| Parker | 186 | 32 | | 92 |
| Wilcock & Crowe | 36 | 162 | | 475 |
| Average | | | 166 | |

750 cfs

| SRH Equation | Flushed Mass ($yd^3$/hr) | Flush Time (hr) | Ratio to RAS | HEC-RAS Flush Estimate (hr) |
|---|---|---|---|---|
| Meyer Peter Muller | 356 | 25 | 1.70 | 42 |
| Yang | 1,358 | 6 | | 11 |
| Parker | 232 | 38 | | 64 |
| Wilcock & Crowe | 49 | 181 | | 308 |
| Average | | | 106 | |

1,000 cfs

| SRH Equation | Flushed Mass ($yd^3$/hr) | Flush Time (hr) | Ratio to RAS | HEC-RAS Flush Estimate (hr) |
|---|---|---|---|---|
| Meyer Peter Muller | 455 | 29 | 1.00 | 29 |
| Yang | 2,128 | 6 | | 6 |
| Parker | 312 | 42 | | 42 |
| Wilcock & Crowe | 72 | 184 | | 184 |
| Average | | | 65 | |

1,250 cfs

| SRH Equation | Flushed Mass ($yd^3$/hr) | Flush Time (hr) | Ratio to RAS | HEC-RAS Estimate (hr) |
|---|---|---|---|---|
| Meyer Peter Muller | 635 | 23 | 1.07 | 25 |
| Yang | 2,548 | 6 | | 6 |
| Parker | 314 | 47 | | 50 |
| Wilcock & Crowe | 72 | 205 | | 220 |
| Average | | | 76 | |

2,500 cfs

| SRH Equation | Flushed Mass ($yd^3$/hr) | Flush Time (hr) | Ratio to RAS | HEC-RAS Flush Estimate (hr) |
|---|---|---|---|---|
| Meyer Peter Muller | 1,141 | 14 | 1.03 | 14 |
| Yang | 7,334 | 2 | | 2 |
| Parker | 637 | 24 | | 25 |
| Wilcock & Crowe | 177 | 88 | | 90 |
| Average | | | 33 | |