MS
CIVIL CONSULTANTS, INC.

April 25, 2024

El Paso County
Planning & Community Development
2880 International Circle, Suite 110
Colorado Springs, CO 80910

Attn.: Project Manager

RE: Claremont Business Park Filing No. 1A, Lot 2, Private Detention/Stormwater Quality Pond - Asbuilt Certification
EPC Project # PPR-192

Dear Project Manager:

Per the approved construction drawings for " Claremont Business Park Filing No. 1A, Lot 2", improvements were made to construct a water quality facility in compliance with the current El Paso County Drainage Criteria and the approved Final Drainage Report for this project.

Based upon this information and periodic site visits to the project during significant/key phases of the stormwater BMP installation, M&S Civil Consultants, Inc. is of the opinion that the stormwater BMPs have been constructed in general compliance with the approved design plans, and specifications as filed with El Paso County. The site and adjacent properties (as affected by work performed under for this project EPC #PPR-192) are stable with respect to settlement and subsidence, sloughing of cut and fill slopes, revegetation or other ground cover, and the improvements (private) meet or exceed the minimum design requirements. The facilities provide the required storage volume and will meet the required release rates, as documented by an attached UDFCD design form submitted with the original application, the stage areas, elevations and outlet dimensions.

<u>Statement Of Engineer In Responsible Charge</u>

To the best of my knowledge, information and belief, for the referenced project above, the improvements have been constructed in general compliance with the approved design plans and specifications as filed with El Paso County.

Virgil A. Sanchez
Colorado P.E. No.37160
For and on behalf of M&S Civil Consultants, Inc.

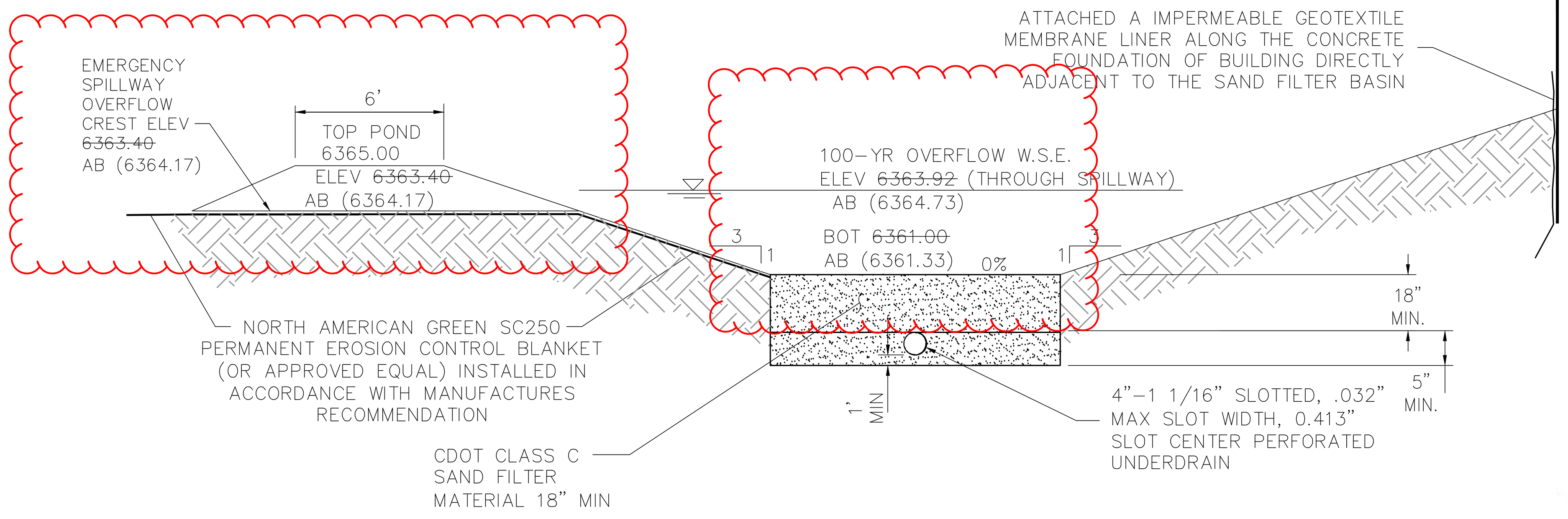
COLORADO REGISTERED PROFESSIONAL ENGINEER
VIRGIL A. SANCHEZ
37160
04/26/24

CLAREMONT BUSINESS PARK FIL NO. 1A, LOT 2

COUNTY OF EL PASO, STATE OF COLORADO

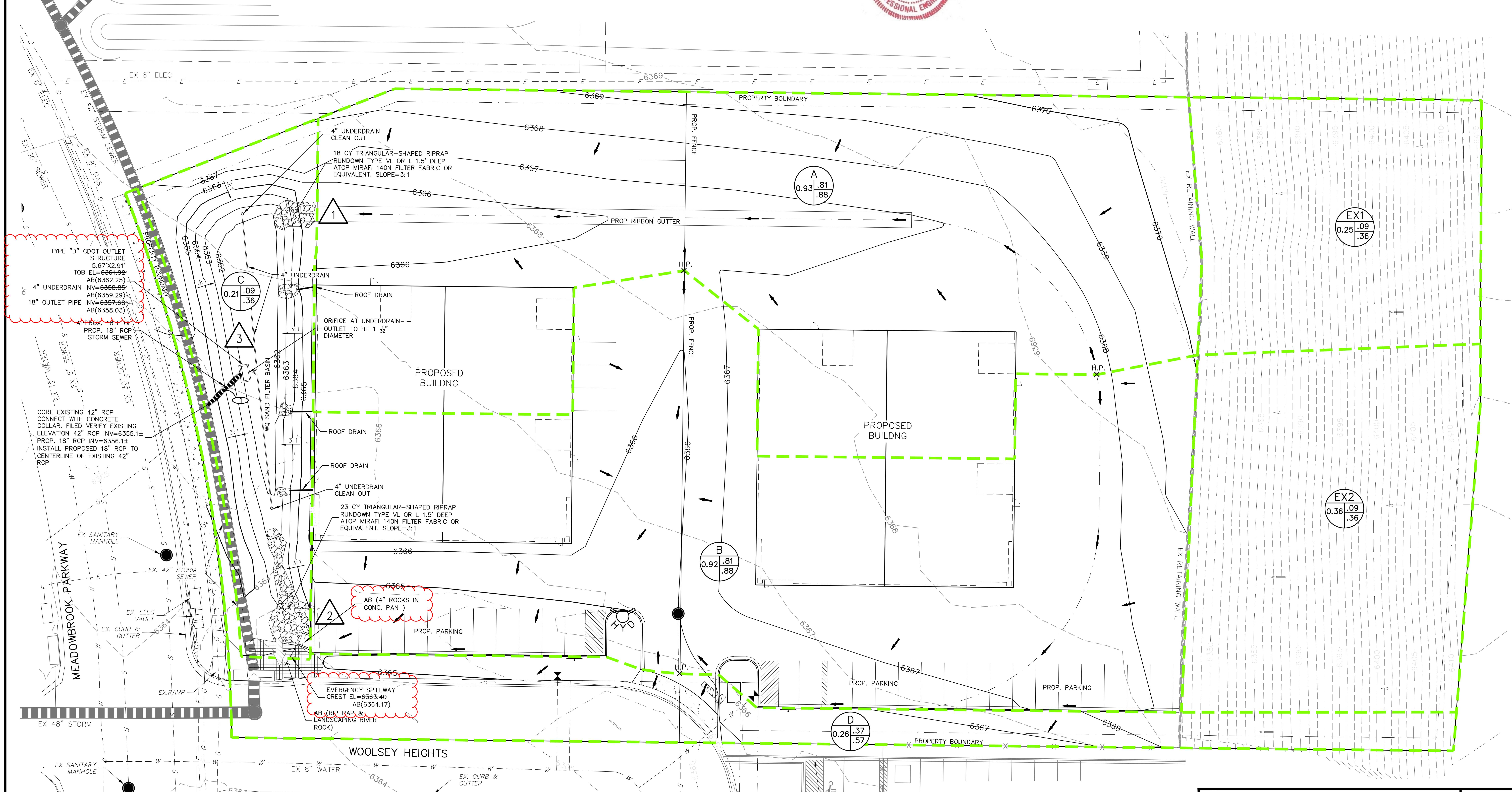
ASBUILT - DRAINAGE MAP

APRIL 2024



SAND FILTER BASIN AND SPILLWAY DETAIL
(NOT TO SCALE)

COLORADO REGISTERED PROFESSIONAL ENGINEER 37160 04/26/24



LEGEND

- BASIN DESIGNATION / ACRES / C5 / C100
- PIPE RUN REFERENCE LABEL
- SURFACE DESIGN POINT
- BASIN BOUNDARY
- EXISTING CONTOUR
- PROP CONTOUR
- SITE BOUNDARY
- PROPOSED STORM SEWER PIPE
- EXISTING STORM SEWER PIPE
- CROSSPAN
- INLET
- EXISTING FLOW DIRECTION ARROW
- EMERGENCY OVERFLOW DIRECTION
- PROPOSED FLOW DIRECTION
- HIGH POINT
- LOW POINT
- SC250 PERM. EROSION CONTROL MAT
- RIPRAP TYPE VL OR L

BASIN SUMMARY

BASIN	AREA (ACRES)	Q_5	Q_{100}
EX1	0.25	0.1	0.8
EX2	0.36	0.2	1.1
A	0.93	3.9	7.0
B	0.92	3.8	7.0
C	0.21	0.1	0.6
D	0.26	0.5	1.2

DESIGN POINT SUMMARY

DESIGN POINT	Q_5	Q_{100}	BASIN	STRUCTURE
1	3.7	7.3	EX1, A	RUNDOWN TO SFB
2	3.7	7.5	EX2, B	RUNDOWN TO SFB
3	7.5	15.4	DP1, DP2, C	WQ SAND FILTER BASIN & OUTLET STRUCTURE

STORM SEWER SUMMARY

PIPE RUN	Q_5	Q_{100}	PIPE SIZE	CONTRIBUTING PIPES
1	7.5	15.4	18" RCP	DP3/SFB

WQCV SUMMARY

EPC/URBAN DRAINAGE SAND FILTER BASIN-SEE STD. DET.		ASBUILT
WQCV PROVIDED	0.042 AF	0.042 AF
AREA REQUIRED	965 SF	965 SF
AREA PROVIDED	1,580 SF	1,239 SF
100 YR WATER SURFACE EL	6362.45	6362.77
EMERGENCY SPILLWAY CREST ELEVATION	6363.40 FT	6364.17
SPILLWAY DESIGN FLOW DEPTH	0.52 FT	*0.56 FT
CDOT TYPE D OUTLET STRUCTURE TOB ELEVATION	6361.92 FT	6362.25

*VALUE PER UD-DET WORKSHEET

1" = 20'

0 10' 20' 40'
Scale in Feet

FOR LOCATING & MARKING GAS, ELECTRIC, WATER & TELEPHONE LINES
FOR BURIED UTILITY INFORMATION
48 HRS BEFORE YOU DIG
CALL 1-800-922-1987

ASBUILT PLAN

M&S CIVIL CONSULTANTS, INC.
20 BOULDER CRESCENT, SUITE 110
COLORADO SPRINGS, CO 80903
PHONE: 719.955.5485

CBP LOT 2-1A

ASBUILT - DRAINAGE MAP

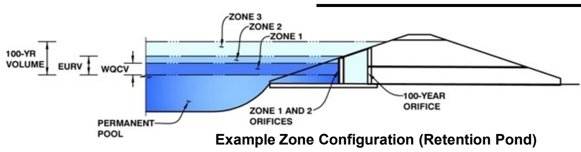
PROJECT NO. 44-034	SCALE: HORIZONTAL: 1"=20' VERTICAL: N/A	DATE: 04/24/2024	
DESIGNED BY: CMN DRAWN BY: CMN CHECKED BY: VAS		SHEET 1 OF 1	PDM

Detention Basin Outlet Structure Design

UD-Detention, Version 3.07 (February 2017)

Project: CBP LOT 2-1A

Basin ID:



Example Zone Configuration (Retention Pond)

	Stage (ft)	Zone Volume (ac-ft)	Outlet Type
Zone 1 (WQCV)	0.90	0.046	Filtration Media
Zone 2			
Zone 3			
		0.046	Total

User Input: Orifice at Underdrain Outlet (typically used to drain WQCV in a Filtration BMP)

Underdrain Orifice Invert Depth =	2.04	ft (distance below the filtration media surface)
Underdrain Orifice Diameter =	1.04	inches

Calculated Parameters for Underdrain

Underdrain Orifice Area =	0.0	ft^2
Underdrain Orifice Centroid =	0.04	feet

User Input: Orifice Plate with one or more orifices or Elliptical Slot Weir (typically used to drain WQCV and/or EURV in a sedimentation BMP)

Invert of Lowest Orifice =		ft (relative to basin bottom at Stage = 0 ft)
Depth at top of Zone using Orifice Plate =		ft (relative to basin bottom at Stage = 0 ft)
Orifice Plate: Orifice Vertical Spacing =		inches
Orifice Plate: Orifice Area per Row =		inches

Calculated Parameters for Plate

WQ Orifice Area per Row =	N/A	ft^2
Elliptical Half-Width =	N/A	feet
Elliptical Slot Centroid =	N/A	feet
Elliptical Slot Area =	N/A	ft^2

User Input: Stage and Total Area of Each Orifice Row (numbered from lowest to highest)

	Row 1 (optional)	Row 2 (optional)	Row 3 (optional)	Row 4 (optional)	Row 5 (optional)	Row 6 (optional)	Row 7 (optional)	Row 8 (optional)
Stage of Orifice Centroid (ft)								
Orifice Area (sq. inches)								

	Row 9 (optional)	Row 10 (optional)	Row 11 (optional)	Row 12 (optional)	Row 13 (optional)	Row 14 (optional)	Row 15 (optional)	Row 16 (optional)
Stage of Orifice Centroid (ft)								
Orifice Area (sq. inches)								

User Input: Vertical Orifice (Circular or Rectangular)

	Not Selected	Not Selected	
Invert of Vertical Orifice =			ft (relative to basin bottom at Stage = 0 ft)
Depth at top of Zone using Vertical Orifice =			ft (relative to basin bottom at Stage = 0 ft)
Vertical Orifice Diameter =			inches

Calculated Parameters for Vertical Orifice

	Not Selected	Not Selected	
Vertical Orifice Area =			ft^2
Vertical Orifice Centroid =			feet

User Input: Overflow Weir (Dropbox) and Grate (Flat or Sloped)

	Not Selected	Not Selected	
Overflow Weir Front Edge Height, Ho =	0.92		ft (relative to basin bottom at Stage = 0 ft)
Overflow Weir Front Edge Length =	5.67		feet
Overflow Weir Slope =	0.00		H:V (enter zero for flat grate)
Horiz. Length of Weir Sides =	2.91		feet
Overflow Grate Open Area % =	70%		%, grate open area/total area
Debris Clogging % =	50%		%

Calculated Parameters for Overflow Weir

	Not Selected	Not Selected	
Height of Grate Upper Edge, H_t =	0.92		feet
Over Flow Weir Slope Length =	2.91		feet
Grate Open Area / 100-yr Orifice Area =	6.54		should be ≥ 4
Overflow Grate Open Area w/o Debris =	11.55		ft^2
Overflow Grate Open Area w/ Debris =	5.77		ft^2

User Input: Outlet Pipe w/ Flow Restriction Plate (Circular Orifice, Restrictor Plate, or Rectangular Orifice)

	Not Selected	Not Selected	
Depth to Invert of Outlet Pipe =	3.30		ft (distance below basin bottom at Stage = 0 ft)
Circular Orifice Diameter =	18.00		inches

Calculated Parameters for Outlet Pipe w/ Flow Restriction Plate

	Not Selected	Not Selected	
Outlet Orifice Area =	1.77		ft^2
Outlet Orifice Centroid =	0.75		feet
Half-Central Angle of Restrictor Plate on Pipe =	N/A	N/A	radians

User Input: Emergency Spillway (Rectangular or Trapezoidal)

Spillway Invert Stage=	2.84	ft (relative to basin bottom at Stage = 0 ft)
Spillway Crest Length =	10.20	feet
Spillway End Slopes =	4.00	H:V
Freeboard above Max Water Surface =	1.00	feet

Calculated Parameters for Spillway

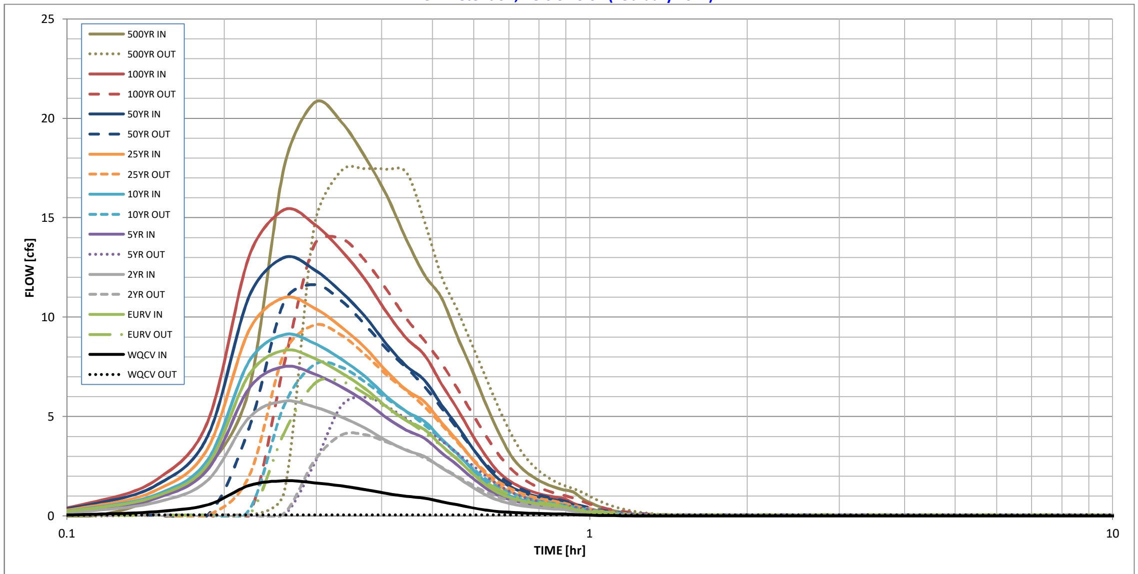
Spillway Design Flow Depth=	0.56	feet
Stage at Top of Freeboard =	4.40	feet
Basin Area at Top of Freeboard =	0.15	acres

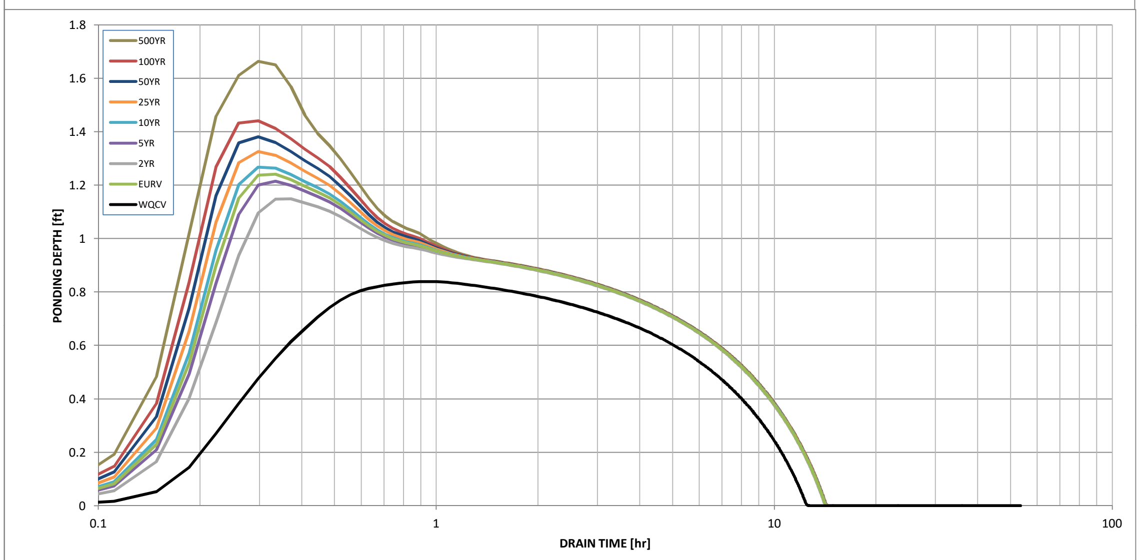
Routed Hydrograph Results

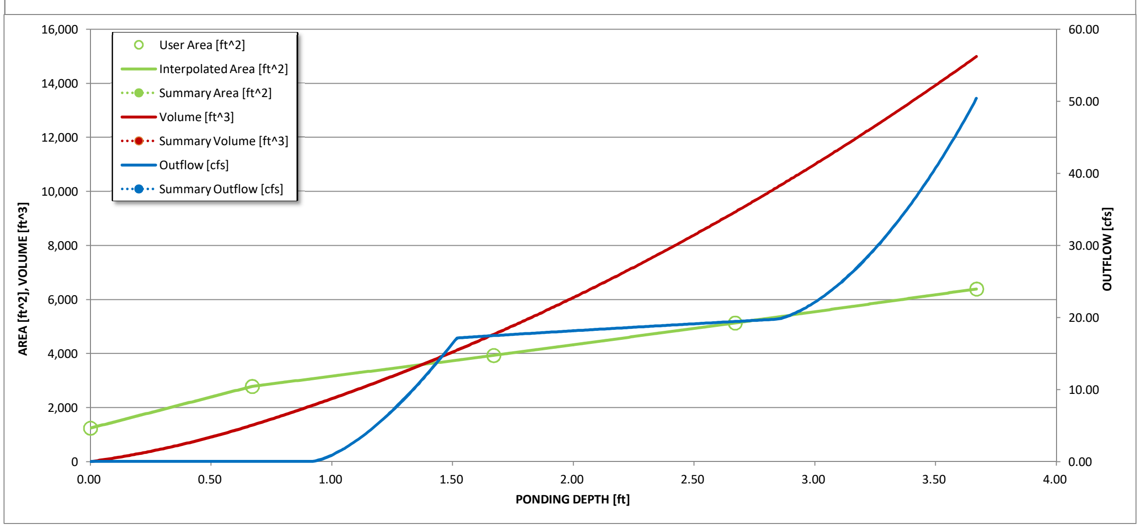
Design Storm Return Period =	WQCV	EURV	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year	500 Year
One-Hour Rainfall Depth (in) =	0.53	1.07	1.19	1.50	1.75	2.00	2.25	2.52	3.14
Calculated Runoff Volume (acre-ft) =	0.046	0.221	0.152	0.199	0.242	0.292	0.347	0.411	0.557
OPTIONAL Override Runoff Volume (acre-ft) =									
Inflow Hydrograph Volume (acre-ft) =	0.046	0.221	0.152	0.199	0.242	0.292	0.347	0.411	0.557
Predevelopment Unit Peak Flow, q (cfs/acre) =	0.00	0.00	0.00	0.01	0.02	0.04	0.27	0.64	1.42
Predevelopment Peak Q (cfs) =	0.0	0.0	0.0	0.0	0.0	0.1	0.7	1.7	3.8
Peak Inflow Q (cfs) =	1.8	8.3	5.8	7.5	9.1	11.0	13.0	15.4	20.8
Peak Outflow Q (cfs) =	0.0	6.8	4.1	6.0	7.6	9.6	11.6	14.0	17.5
Ratio Peak Outflow to Predevelopment Q =	N/A	N/A	N/A	321.7	176.1	99.7	16.3	8.1	4.6
Structure Controlling Flow =	Filtration Media	Overflow Grate 1	Overflow Grate 1	Overflow Grate 1	Overflow Grate 1	Overflow Grate 1	Overflow Grate 1	Overflow Grate 1	Outlet Plate 1
Max Velocity through Grate 1 (fps) =	N/A	0.55	0.33	0.5	0.6	0.8	1.0	1.2	1.5
Max Velocity through Grate 2 (fps) =	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Time to Drain 97% of Inflow Volume (hours) =	12	12	13	13	12	12	11	11	10
Time to Drain 99% of Inflow Volume (hours) =	**12**	14	14	14	14	13	13	13	13
Maximum Ponding Depth (ft) =	0.84	1.24	1.15	1.21	1.27	1.33	1.38	1.44	1.66
Area at Maximum Ponding Depth (acres) =	0.07	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09
Maximum Volume Stored (acre-ft) =	0.042	0.072	0.064	0.069	0.073	0.078	0.083	0.088	0.107

Detention Basin Outlet Structure Design

UD-Detention, Version 3.07 (February 2017)







S-A-V-D Chart Axis Override	X-axis	Left Y-Axis	Right Y-Axis
minimum bound			
maximum bound			

Detention Basin Outlet Structure Design

Outflow Hydrograph Workbook Filename:

Storm Inflow Hydrographs UD-Detention, Version 3.07 (February 2017)

The user can override the calculated inflow hydrographs from this workbook with inflow hydrographs developed in a separate program.

Time Interval	Hydrograph Constant
2.23 min	2.244

SOURCE	WORKBOOK	WORKBOOK	WORKBOOK	WORKBOOK	WORKBOOK	WORKBOOK	WORKBOOK	WORKBOOK	WORKBOOK
TIME	WQCV [cfs]	EURV [cfs]	2 Year [cfs]	5 Year [cfs]	10 Year [cfs]	25 Year [cfs]	50 Year [cfs]	100 Year [cfs]	500 Year [cfs]
0:00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0:02:14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0:04:28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0:06:41	0.08	0.38	0.26	0.34	0.41	0.49	0.58	0.69	0.92
0:08:55	0.22	1.01	0.70	0.91	1.10	1.32	1.56	1.85	2.48
0:11:09	0.56	2.59	1.80	2.34	2.83	3.40	4.02	4.75	6.39
0:13:23	1.54	7.12	4.94	6.42	7.78	9.34	11.05	13.05	17.55
0:15:37	1.77	8.33	5.77	7.51	9.12	10.97	13.01	15.40	20.79
0:17:50	1.67	7.93	5.48	7.14	8.68	10.45	12.39	14.67	19.83
0:20:04	1.52	7.21	4.98	6.50	7.89	9.50	11.27	13.35	18.05
0:22:18	1.33	6.40	4.41	5.77	7.01	8.45	10.04	11.90	16.11
0:24:32	1.13	5.49	3.77	4.94	6.01	7.26	8.63	10.24	13.90
0:26:46	0.99	4.80	3.30	4.32	5.25	6.34	7.53	8.94	12.11
0:28:59	0.89	4.34	2.98	3.90	4.75	5.74	6.82	8.09	10.97
0:31:13	0.72	3.54	2.42	3.18	3.88	4.70	5.59	6.65	9.04
0:33:27	0.57	2.86	1.95	2.57	3.14	3.81	4.54	5.41	7.38
0:35:41	0.41	2.16	1.46	1.94	2.38	2.89	3.46	4.13	5.67
0:37:55	0.29	1.58	1.06	1.41	1.74	2.12	2.55	3.05	4.21
0:40:08	0.22	1.16	0.78	1.04	1.27	1.55	1.86	2.22	3.05
0:42:22	0.18	0.91	0.62	0.81	1.00	1.21	1.45	1.73	2.37
0:44:36	0.15	0.75	0.51	0.67	0.82	1.00	1.19	1.42	1.95
0:46:50	0.13	0.64	0.43	0.57	0.70	0.85	1.02	1.21	1.66
0:49:04	0.11	0.56	0.38	0.50	0.62	0.75	0.89	1.06	1.45
0:51:17	0.10	0.51	0.35	0.46	0.56	0.68	0.81	0.96	1.31
0:53:31	0.10	0.47	0.32	0.42	0.52	0.63	0.75	0.89	1.21
0:55:45	0.07	0.35	0.24	0.31	0.38	0.46	0.55	0.65	0.89
0:57:59	0.05	0.25	0.17	0.23	0.28	0.34	0.40	0.48	0.65
1:00:13	0.04	0.18	0.13	0.17	0.20	0.25	0.29	0.35	0.48
1:02:26	0.03	0.13	0.09	0.12	0.15	0.18	0.21	0.26	0.35
1:04:40	0.02	0.09	0.06	0.09	0.10	0.13	0.15	0.18	0.25
1:06:54	0.01	0.07	0.05	0.06	0.07	0.09	0.11	0.13	0.18
1:09:08	0.01	0.05	0.03	0.04	0.05	0.06	0.08	0.09	0.13
1:11:22	0.00	0.03	0.02	0.03	0.03	0.04	0.05	0.06	0.08
1:13:35	0.00	0.02	0.01	0.01	0.02	0.02	0.03	0.03	0.05
1:15:49	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.02	0.02
1:18:03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1:20:17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:22:31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:24:44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:26:58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:29:12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:31:26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:33:40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:35:53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:38:07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:40:21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:42:35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:44:49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:47:02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:49:16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:51:30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:53:44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:55:58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1:58:11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:00:25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:02:39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:04:53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:07:07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:09:20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:11:34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:13:48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:16:02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:18:16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:20:29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:22:43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:24:57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:27:11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:29:25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:31:38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:33:52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:36:06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:38:20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2:40:34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Vermont Stream Geomorphic Assessment

Appendix O

Particle Entrainment and Transport

Vermont Agency of Natural Resources
April, 2004

Particle Entrainment and Transport

Introduction

What follows is an introduction to basic concepts associated with measurement and prediction of entrainment and transport of bed material in natural rivers. The purpose of this discussion is to familiarize the reader with methods for predicting particle entrainment and their limitations. This discussion does not represent the full breadth of study and research on this subject matter. Rather it introduces core principles and gives background on methods of entrainment prediction most commonly used by river management practitioners.

The Importance of Bedload Transport: Understanding characteristics of sediment transport benefits many applications including prediction of the effects of land use or flow regime change and channel restoration efforts (Wilcock, 2001). The relationship between discharge and bedload transport rate through a reach and the ability of the existing channel to transport the bedload (sediment transport capacity) is critical to the establishment of river equilibrium in river corridor protection and restoration efforts. Measuring the size and quantity of bedload particles moving through a reach at different discharges and developing a sediment rating curve is the ideal predictive tool for project design. Once the conditions required for bedload transport are known they can be translated into an understanding of the channel dimension, pattern, and profile that will result in sufficient transport of the expected sediment supply.

Measuring Bedload Transport: Unfortunately, bedload transport is not simple to measure or predict. It is a sporadic process that occurs through a variety of mechanisms. Its variability both spatially and temporally add to the difficulty. Bedload measurement is particularly challenging for river managers to conduct due to its high cost and the length of time over which it takes to accurately complete. Additionally, sampling devices placed in the flow may perturb local hydraulics sufficiently to create anomalously high or low transport conditions (Wohl, 2000). Despite these difficulties, efforts to understand bed-load transport and its relation to flow discharge are worthwhile and can lead to better assessment and project design.

Sediment Entrainment Calculation

In lieu of creating sediment rating curves on a project by project basis, practitioners have had fairly good results using empirically derived equations for the prediction of the conditions necessary to entrain bed particles and designing channels to produce those conditions. While the first efforts in this area resulted in equations that were accurate only when applied to channels with homogeneous bed sediments, more recent efforts have resulted in equations that are applicable to natural rivers.

The parameter often used as a measure of the stream's ability to entrain bed material is the shear stress created by the flow acting on the bed material. Shear stress acts in the direction of the flow as it slides along the channel bed and banks. Critical shear stress is the shear stress required to mobilize sediments delivered to the channel. When the shear stress equals the critical shear stress, the channel will likely be in equilibrium. Where shear stress is excessively greater than critical shear stress, channel degradation will likely result. Where the shear stress is less than critical shear stress, channel aggradation will likely result. Thus the ability to calculate or measure both shear and critical shear stress is crucial in understanding channel adjustments.

Calculating Shear Stress: Unfortunately, attempts to calculate or measure shear stress values in mountain rivers are complicated by the channel bed roughness and the associated turbulence and velocity fluctuations (Wohl, 2000). Turbulence can lead to substantial variability in velocity and shear stress at a point during constant discharge. Heterogeneities caused by grains and bedforms may create substantial velocity and shear stress variations across the channel or downstream during a constant discharge. Despite these issues measurement of the general shear stress in a reach is feasible and useful.

Based upon the physical properties involved, the following theoretical equation for general shear stress has been developed.

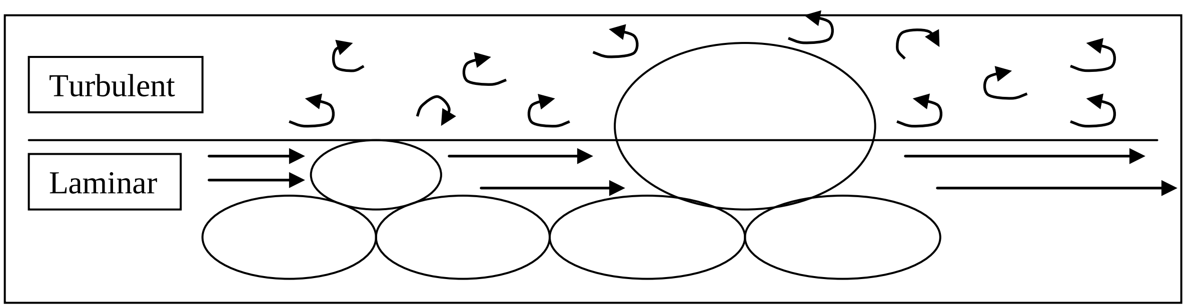
$$\tau = \gamma R s \text{ (lbs./sq.ft.)},$$

where τ is the fluid shear stress
γ is the specific gravity of water
(density x gravitational acceleration)
(1.94 slugs x 32.2 ft/sq.sec) = 62.4 lbs./sq.ft.
R is the hydraulic radius (approximately mean depth)
s is the slope of the channel

The Physical Properties Involved
Initiation of motion involves mass, force, friction and stress. Gravity and friction are the two primary forces in play as water flows through a channel. Gravity acts upon water to move it down slope. Friction exerted on the water by the bed and banks of the channel works to slow the movement of the water. When the force of gravity is equal and opposite to the force of friction the water flows through the channel at a constant velocity. When the force of gravity is greater than the force of friction the water accelerates (Leopold et.al., 1964).

Shear Stress vs. a Particle Resistance to Movement: A given particle will move only when the shear stress acting on it is greater than the resistance of the particle to movement. The magnitude of shear stress required to move a given particle is known as the critical shear stress (τ_{cr}). The resistance of the particles to movement and thus its entrainment will vary depending on its size, its size relative to surrounding particles, how it is oriented and the degree to which it is embedded. The size of the particle will influence the weight of the particle. The size of the particles relative to surrounding particles will affect the amount of shear stress the particle is exposed to via the “hiding” factor. Orientation of the particle will affect the force required to roll the particle along the bed. Packing or embeddedness will affect the amount of shear stress that the particle is exposed to.

Because of turbulence the hiding affect may be the primary factor in determining critical shear stress. Turbulence can result in shear stress spikes that are four times greater than the average shear stress. Thus a particle exposed to turbulence will experience greater fluid force than a particle not exposed to the turbulence. There is a layer of water just above the stream bed that is not turbulent. The thickness of this layer is sufficient to cover the average particle size of the bed. A larger particle however, will extend above this zone of non-turbulent flow and be exposed to turbulent flow. Thus, a particle surrounded by smaller particles will experience turbulence while a particle that is the same size as the average bed size will experience only non-turbulent flow and thus be exposed to less fluid shear stress. Accurate estimations of critical shear stress requires accurate characterization of these parameters (Wohl, 2000).



Calculating Critical Shear Stress: With the above principles in mind, Shields in 1936 conducted flume experiments to develop an expression for the critical shear stress to move a particle of a given size (Knighton, 1998). His work resulted in the following equation:

$$\tau_{cr} = \tau_{ci} \times g(\rho_s - \rho_w)d$$

where;

τ_{cr} is critical shear stress,
τ_{ci} is dimensionless critical shear stress,
g is acceleration due to gravity,
ρ_s is the density of sediment,
ρ_{ws} is the density of water; and
d is the size of the particle of interest.

Shields' studies showed that in gravel bed channels of homogeneous sediment sizes and turbulent flow the value of dimensionless critical shear stress is 0.06. Shields' still serves as a basis for defining critical shear stress (Fischenich, 2001). However, since Sheilds' work other researchers have developed derivations of Shields' equation in an effort to improve the prediction of critical shear in natural channels with heterogeneous substrate sizes.

Fischenich, (2001) lists the following equations presented by Julien to approximate the critical shear stress for particles of various sizes.

$$\tau_{cr} = 0.5 \times g(\rho_s - \rho_w)d \times Tan\phi \quad \text{:For clays}$$
$$\tau_{cr} = 0.25 d_*^{-0.6} \times g(\rho_s - \rho_w)d \times Tan\phi \quad \text{:For silts and sands}$$
$$\tau_{cr} = 0.06 \times g(\rho_s - \rho_w)d \times Tan\phi \quad \text{:For gravels and cobbles}$$

Where;

$$d_* = d\left[\frac{(G-1)g}{v^2}\right]^{1/3}$$

ϕ is the angle of repose of the particle
G is the specific gravity of sediment
g is acceleration due to gravity,
ρ_s is the density of sediment,
ρ_{ws} is the density of water
v is the kinematic velocity; and
d is the size of the particle of interest.

Angles of repose are given in Table 1 (Julien, 1995). Critical shear stresses are also provided in Table 1. It is important to realize that mixtures of sediments behave differently than uniform sediments. Particles larger than the median will be entrained at shear stresses lower than those given in Table 1 and, conversely, larger shear stresses than those listed in the table are required to entrain particles smaller than the median size (Fischenich, 2001).

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Project:

Date:

$\tau = \gamma \times d \times S$

τ = shear stress (#/sqft)
γ = unit weight of water (#/ft^3)
d = depth of flow (ft)
S = energy gradient (ft/ft)

Assume S = slope (Assumed) ground

$62.4 \times 6.2''/12.0 \times 0.005 = 0.1612$ #/ft

flowmaster (see attached sheet)

Worksheet for landscaping rock spillway x-section

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.033
Channel Slope	0.005 ft/ft
Left Side Slope	10.000 H:V
Right Side Slope	4.000 H:V
Bottom Width	10.21 ft
Discharge	15.40 cfs

Results

Normal Depth	6.9 in
Flow Area	8.3 ft²
Wetted Perimeter	18.4 ft
Hydraulic Radius	5.4 in
Top Width	18.31 ft
Critical Depth	4.5 in
Critical Slope	0.024 ft/ft
Velocity	1.87 ft/s
Velocity Head	0.05 ft
Specific Energy	0.63 ft
Froude Number	0.490
Flow Type	Subcritical

GVF Input Data

Downstream Depth	0.0 in
Length	0.0 ft
Number Of Steps	0

GVF Output Data

Upstream Depth	0.0 in
Profile Description	N/A
Profile Headloss	0.00 ft
Downstream Velocity	0.00 ft/s
Upstream Velocity	0.00 ft/s
Normal Depth	6.9 in
Critical Depth	4.5 in
Channel Slope	0.005 ft/ft
Critical Slope	0.024 ft/ft

Table 1 Limiting Shear Stress and Velocity For Uniform Noncohesive Sediments

Class name	d_s (in)	ϕ (deg)	τ_c	τ_{cr} (lb/sf)	V_{*c} (ft/s)
Boulder					
Very large	>80	42	0.054	37.4	4.36
Large	>40	42	0.054	18.7	3.08
Medium	>20	42	0.054	9.3	2.20
Small	>10	42	0.054	4.7	1.54
Cobble					
Large	>5	42	0.054	2.3	1.08
Small	>2.5	41	0.052	1.1	0.75
Gravel					
Very coarse	>1.3	40	0.050	0.54	0.52
Coarse	>0.6	38	0.047	0.25	0.36
Medium	>0.3	36	0.044	0.12	0.24
Fine	>0.16	35	0.042	0.06	0.17
Very fine	>0.08	33	0.039	0.03	0.12
Sands					
Very coarse	>0.04	32	0.029	0.01	0.070
Coarse	>0.02	31	0.033	0.006	0.055
Medium	>0.01	30	0.048	0.004	0.045
Fine	>0.005	30	0.072	0.003	0.040
Very fine	>0.003	30	0.109	0.002	0.035
Silts					
Coarse	>0.002	30	0.165	0.001	0.030
Medium	>0.001	30	0.25	0.001	0.025

coarse gravel any particles greater than 0.19" generally range between 3/8/ and 1"

required 0.16 provided 0.25

Since Shields conducted his work further research has shown that τ_{ci} can range from 0.25-0.02 depending upon the size distribution of the bed particles. Andrews (1984) showed that τ_{ci} can be calculated using the following equation:

$$\tau^*_{ci} = 0.0834\left(\frac{d_i}{d_{S_{50}}}\right)^{-0.872}$$

where;

d_i is the particle size of interest

$d_{S_{50}}$ is the median particle size of the sub-surface

Andrews equation can be used to calculate τ^*_{ci} which can then be used in the Shields equation to determine the critical shear stress required to move a particle of a given size in gravel-cobble bed streams. As discussed in Step 2.7 of the Phase 3 handbook, d_i and $d_{S_{50}}$ can be determined through field sampling.

Cautions and the use of Multiple Methodologies

It is important to remember that the equations presented above, while used widely, are not used exclusively. The predictive tools presented here are understood to be general in nature and may not be appropriate for all situations. As stated above there are many variables associated with measurement or calculation of shear stress, critical shear stress and bed-load transport. Despite the uncertainties, the weighing of river management alternatives will benefit from attempts to develop as accurate an understanding as possible. Otherwise, assessment, river corridor protection, and restoration efforts are less likely to meet established goals. Careful use of prediction and application methods and an understanding of the limitations of those methods, will greatly improve project outcomes and helps explain the variables and uncertainties that are inherent in river assessment and management work. Following these guidelines will increase the likelihood of success.

- **Increase your own expertise by reviewing the literature**. Below is a list references that pertain to the subject of sediment transport processes. A review of this literature will greatly increase your understanding of the methods for analyzing sediment transport processes and associated limitations.
- **Employ multiple methodologies and seek convergence.** Methods for calculation and measurement of shear stress and critical shear stress are described above. This is by no means a complete list: nor are the individual methods in the list preferred by the River management Program. Use as many various analyses as possible given particular circumstances and evaluate the results on how well they agree with other data pertaining to the project or assessment.

References

1. Andrews, E.D., Entrainment of Gravel From Naturally Sorted Riverbed Material. Geological Society of America Bulletin, v.94, p. 1225-1231, October 1983.

2. Knighton, D., Fluvial Forms and Processes A New Perspective. 1998. Oxford University Press Inc. New York.

3. Fischenich. 2001. Stability Thresholds for Stream Restoration Materials. EMRRP Technical Notes Collection (ERDC TN-EMRRP-SR-29), U.S. Army Engineer Research and Development Center, Vicksburg, M.S. www.wes.army.mil/e/emrrp

4. Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Co. San Fransisco.

5. Wohl, E. 2000. Mountain Rivers. American Geophysical Union. Washington, D.C.

6. Wilcock, P.R. Toward a Practical Method For Estimating Sediment Transport Rates in Gravel Bed Rivers. Earth Surface Processes and Landforms, v.26, p. 1395-1408, September 2001.