Appendix L

Design Calculations

L-1

Sedimentation Trap Design Calculations

Foth

Memorandum

11/30/07

TO: Files – Nagawicka Lake Dredging Project

CC: John Starke

FR: Michael D. Liebman, P.E.
Senior Water Resources Engineer

RE: Bark River Inlet Sedimentation Basin Performance

Background

As part of the dredging and improvement effort for Nagawicka Lake, Foth Infrastructure and Environment is evaluating the placement of a sedimentation basin where the Bark River enters the lake. By dredging a large basin below the existing stream and lake bottoms, future sediments carried to the lake by the Bark River can be trapped, providing a longer time period before additional dredging of the lake is needed in the future. This memo summarizes the evaluation of the sediment storage capabilities of the proposed river inlet sedimentation basin.

Bark River Drainage Basin Characteristics

Lake Nagawicka and its tributary drainage basin, has been studied in detail through the years. The following pertinent information was found in the 1999 SEWRPC planning document, "*A Lake and Watershed Inventory for Nagawicka Lake – Waukesha County Wisconsin*",

- Tributary Area – The drainage basin includes 24,189 acres associated with the Bark River and 4,763 acres directly tributary to the Lake.
- Soils – 67% of the soils in the drainage basin are in the more 'sandy' category (hydrologic soil classification "B"), while the remaining soils are silty/light clay ("C" soils – 15%), tight clays ("D" soils – 11%), and water and other soils (7%).
- Precipitation – Annual precipitation within the watershed generally totals 33.5 inches.
- Runoff – Annual runoff within the watershed on average totals 9.88 inches.

The 2001 SEWRPC planning document, "*A Lake Management Plan for Nagawicka Lake – Waukesha County Wisconsin*", provides the other key element for sediment storage performance evaluation,

2737 South Ridge Road, Suite 600 • P.O. Box 12326 • Green Bay, WI 54307-2326 • (920) 497-2500 • Fax: (920) 497-8516

- Sediment Load – Table 2 on page 14 lists the 1995 sediment load to Lake Nagawicka of 3,759 tons (full buildout estimate of 3,625 tons). This estimate includes the entire lake drainage basin.

The final important piece of information pertinent to the sedimentation basin performance is the density of the sediment being delivered to the lake. The following documents present various estimates for this factor,

- 60-135 pound per cubic foot (1971 NAVFAC DM-7 publication "*Soil Mechanics, Foundations, and Earth Structures").*
- 100 pounds per cubic foot (1992 ASCE publication, "*Design and Construction of Urban Stormwater Management Systems*").
- 40-110 pounds per cubic foot (1972 Linsley and Franzini, "*Water Resources Engineering*").

These resources provide the information necessary to evaluate the performance of the proposed sedimentation basin.

Proposed River Inlet Sedimentation Basin

The preliminary sedimentation basin proposed for the Bark River inlet to Lake Nagawicka includes a footprint at the river confluence of nearly 118,000 square feet (2.7 acres). This facility will be dredged down from 4' to over 5' to an elevation of 883.0 (existing bottom elevation in this area ranges from 887 to over 888). The sediment storage available with this facility will total **495,000 cubic feet (11.4 acre-feet)**.

Inlet Sedimentation Basin Performance Evaluation

In order to evaluate the proposed sedimentation basin performance for storing sediment moving down the Bark River into Lake Nagawicka, several calculations and assumptions must be made, as follows,

- Annual sediment yield from the Bark River – As stated above, the sediment yield to Lake Nagawicka from the entire drainage basin in 1995 totaled 3759 tons. Some adjustment to this yield rate must be made because of changes since 1995 and to take into account only sediments moving down the Bark River, as follows,

  Adjustment from 1995 – The 1995 sediment yield of 3,759 tons was reduced to 3,625 tons under full buildout. The expected life of the sedimentation facility will be less than ten years which will not approach the full buildout scenario. To account for the buildout expected during the life of the project, an average sediment yield of **3,692 tons per year** would be a reasonable estimate for the total drainage basin.

Adjustment for the Bark River drainage basin – A straight interpolation calculation using the ratio of the total drainage basin to the Bark River drainage basin can give a reasonable estimate of the sediment yield from the Bark River only. As such, the 3,692 tons/year total basin sediment yield would reduce to **3,085 tons/year from the Bark River**.

- Annual volume of sediment from the Bark River – The volume of sediment moving down the Bark River into the sediment trap can be calculated once the average density of the sediments is known. The cited references suggest that densities might range from 40 to 135 pounds per cubic foot. Based on the generally sandier soils in the drainage basin, it would be reasonable to assume an average density of about 90 pounds per cubic foot. With this average density, the 3,085 tons per year yield would total **68,556 cubic feet per year of sediment (1.57 acre-feet/year).**

- Sedimentation trapping performance – The sediment performance is based on Stokes law, which relates the sediment particle settling velocity to the flow velocity through the basin. Several calculations must be completed to determine the sediment trapping performance of the sedimentation basin, as follows,

  Average Bark River flow rate – The average flow rate of the Bark River can be roughly estimated based on the average runoff over the tributary drainage basin. As previously stated, the annual runoff has been documented to be 9.88". This volume, over the Bark River drainage basin equals 19,916 acre-feet per year which averages out to **27.5 cubic feet per second (cfs)**.

  Particle size settling performance – Stokes law can be broken down to a relationship between the surface area of the sedimentation basin and the particle size that will be dropped out (again, based on settling velocities of various soil particle sizes). With a sedimentation basin surface area size of 117,759 square feet, and an average flow rate of 27.5 cfs, the surface area to outflow ratio equals 4,281 square feet per outflow. Based on the Stokes law relationship, that would provide a settling performance of anything down to a **7 micron sized particle**.

  Trapping efficiency – Because the proposed sedimentation basin is not as controlled as a normal reservoir or sedimentation pond in terms of outflow control structures, the performance of the trap is difficult to predict. Certainly, settlement of soils down to 7 microns (silty clays) would suggest a high level of performance in view of the sandier soils existing in the drainage basin. The ranges of flows (including occasional flood flows) coming from the Bark River, and the lack of a more controlled outlet from the sediment basin, would suggest, however, that a **sediment trap efficiency of perhaps 50%** would be more accurate.

Sedimentation basin life – The expected life of the proposed sedimentation basin is dependant on the available storage, the sediment yield, and the trapping efficiency, as follows,

Available Storage = 11.4 acre-feet

Sediment Yield = 1.57 acre-feet per year

Sedimentation basin life

@ 100% trapping efficiency = 7.2 years
@ 50% trapping efficiency = 14.4 years

Summary

Based on the expected Bark River sediment characteristics and yield, the proposed size of the river inlet sedimentation basin, and the average flow rate, the proposed facility should remove down to 7 micron particles and should have a storage life of from 8 to 15 years.

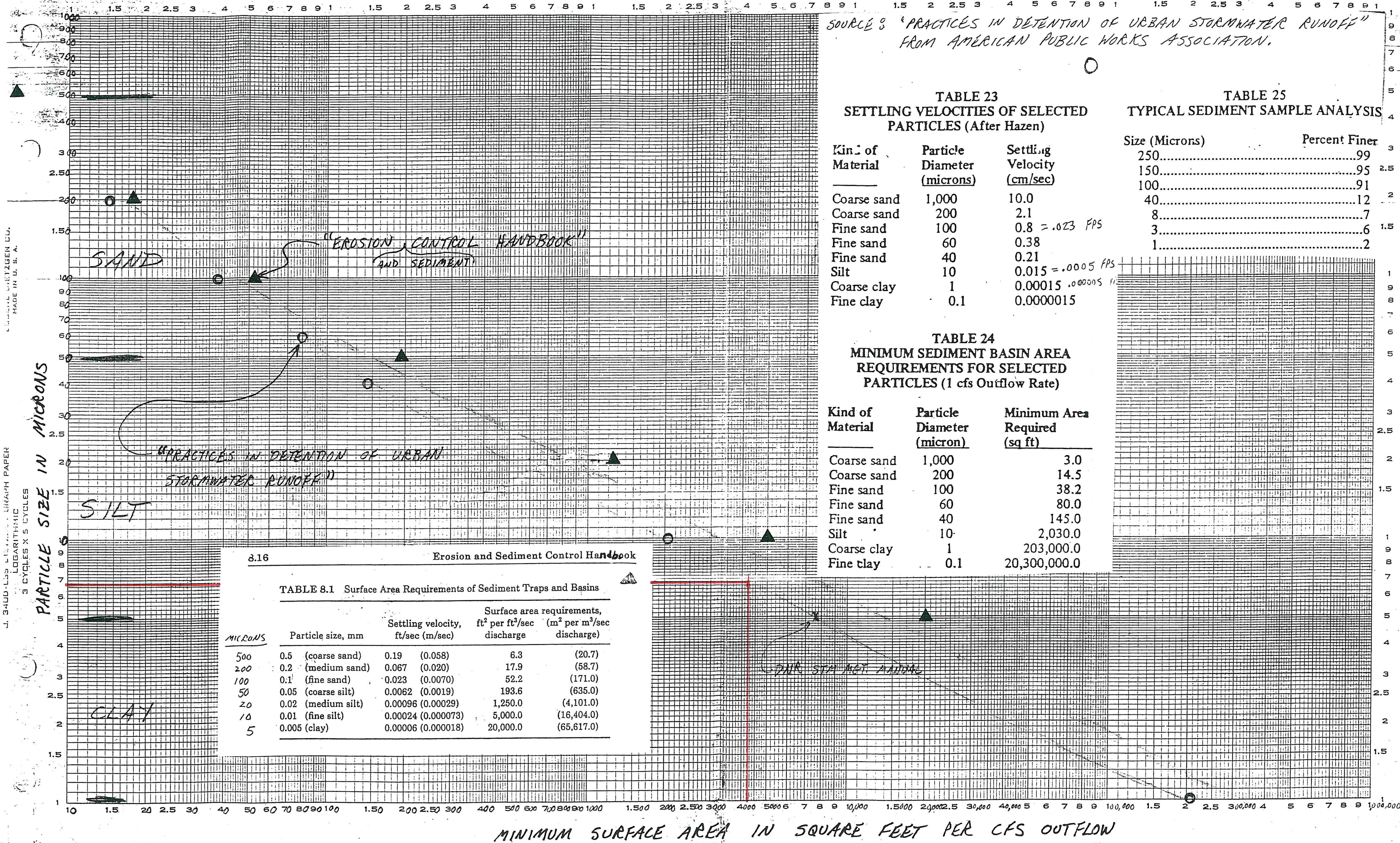

TABLE 23
SETTLING VELOCITIES OF SELECTED PARTICLES (After Hazen)

Kind of Material	Particle Diameter (microns)	Settling Velocity (cm/sec)
Coarse sand	1,000	10.0
Coarse sand	200	2.1
Fine sand	100	0.8 = .023 FPS
Fine sand	60	0.38
Fine sand	40	0.21
Silt	10	0.015 = .0005 FPS
Coarse clay	1	0.00015 .000005
Fine clay	0.1	0.0000015

TABLE 25
TYPICAL SEDIMENT SAMPLE ANALYSIS

Size (Microns)	Percent Finer
250	99
150	95
100	91
40	12
8	7
3	6
1	2

TABLE 24
MINIMUM SEDIMENT BASIN AREA REQUIREMENTS FOR SELECTED PARTICLES (1 cfs Outflow Rate)

Kind of Material	Particle Diameter (micron)	Minimum Area Required (sq ft)
Coarse sand	1,000	3.0
Coarse sand	200	14.5
Fine sand	100	38.2
Fine sand	60	80.0
Fine sand	40	145.0
Silt	10	2,030.0
Coarse clay	1	203,000.0
Fine clay	0.1	20,300,000.0

TABLE 8.1 Surface Area Requirements of Sediment Traps and Basins

MICRONS	Particle size, mm	Settling velocity, ft/sec (m/sec)	Surface area requirements, ft² per ft³/sec discharge	(m² per m³/sec discharge)
500	0.5 (coarse sand)	0.19 (0.058)	6.3	(20.7)
200	0.2 (medium sand)	0.067 (0.020)	17.9	(58.7)
100	0.1 (fine sand)	0.023 (0.0070)	52.2	(171.0)
50	0.05 (coarse silt)	0.0062 (0.0019)	193.6	(635.0)
20	0.02 (medium silt)	0.00096 (0.00029)	1,250.0	(4,101.0)
10	0.01 (fine silt)	0.00024 (0.000073)	5,000.0	(16,404.0)
5	0.005 (clay)	0.00006 (0.000018)	20,000.0	(65,617.0)

L-2

Process Design Calculations and Dewatering Pad Pump Sizing Calculations

Scope

Determine sizing for sediment management area and number of geotextile tubes for dewatering. Also, determine size of effluent booster pump.

The city of Delafield owns an approximately 36-acre parcel of property east of Nagawicka Road and north of Oakwood Lane. The sediment management area is proposed to be located on this property.

Condition

An approximately 36-acre plot of land is available for the proposed sediment management areas. A total of 107,175 cubic yards of sediment (typical in-situ of 20% solids) is anticipated to be placed in the sediment management areas. Dewatering of the sediments will be performed by geotextile tubes placed within a lined 200,000 square foot dewatering pad with a 2-foot high berm on the east and south sides. Carriage water will be pumped into the geotextile tubes. Sediments will be contained within the tubes, while decant water will flow out of the tubes, into the decant water collection system. Following dewatering, the sediment is to be deposited at an estimated 30% to 38% solids.

Assumptions used in this analysis include:

- One dredge operating 24 hours/day, 5 days/week with a capacity of 960 in-situ cubic yards of sediment/day.
- Geotextile dewatering tube capacity of 1,200 cy.
- A 25 year, 24 hour rain event of 4.75 inches (SCS T-55: Urban Hydrology for Small Watersheds. USDA, June 1986).

Calculations

- Determine volume of sediments to be deposited in sediment management area, number of geotextile tubes required, and amount of decant water to be pumped back to Nagawicka Lake. Refer to attached Table 1 for detailed calculations. Sediment volumes were based on dewatered fines contents of 30% (mean) and 38% (maximum). Volume of sediments = 66,574 cubic yards (cy) at 30% solids and 49,482 cubic yards at 38% solids.

- Determine potential for decant water plus precipitation to overtop the 2-foot berm along the east and south sides.

- Assume at initial geotextile tube loading, volume in-situ is required for tube quantity calculations is 107,175 cy.

Number of geotextile tubes required:

107,175 cy ÷ 1,200 cy/bag = approximately **89 bags**

Decant Water Generation @ 30% Solids:

Gallons/day of decant water (from Table 1) = **400,000 gallons**

Decant Water Generation @ 38% Solids:

Gallons/day of decant water (from Table 1) = **430,000 gallons**

Volume of Water Generated by 25 year, 24 hour Rain Event:

4.75 inches * 200,000 square feet * 7.48 gallons/cf ≅ 600,000 gallons

- Determine effluent booster pump sizing for anticipated decant water generated for 30% solids and 38% solids.

Based on a decant water generation rate of 400,000 gallons/day and 430,000 gallons/day, the effluent booster pump should be sized to enable pumping at a rate of 275 to 300 gallons/minute.

Conclusions

Approximately 107,175 cy of in-situ sediments (typical in-situ of 20% solids) is anticipated to be dewatered at the proposed dewatering facility. Using a geotextile dewatering tube volume of 1,200 cy, approximately 89 tubes would be required. Decant water generated will range from 400,000 gallons/day to 430,000 gallons/day at 30% and 38% solids, respectively.

Based on these anticipated decant water volumes, the effluent booster station pump should be sized to pump approximately 275 to 300 gallons/minute.

A 25 year, 24 hour rain event of 4.75 inches will generate approximately 600,000 gallons of water over the 200,000 sf dewatering pad. The approximate volume of water that can be stored in the dewatering pad without overtopping the 2-foot berm along the east and south sides is 750,000 gallons. Therefore, given a pumping rate of 300 gpm, and the worst case scenario of 600,000 gallons of precipitation and 430,000 gallons of decant water into the dewatering pad in a 24 hour period (1,030,000 gallons influent minus 432,000 gallons effluent = 598,000 gallons of storage required), the berms will not be overtopped.

Table 1
Sediment Process Calculations
City of Delafield
Nagawicka Lake Restoration

Foth Infrastructure & Environment, LLC
Green Bay, Wisconsin

in situ characteristics

Volume	**107,175** CY	
% solids	**20%** (typical value)	
Specific Gravity, Gs	**2.5**	
water content	4.00 =Ww/Ws	
dry density	0.19 tons/CY	
bulk density	0.96 tons/CY	*assumes saturation*
dry tons	20,519 tons	
wet tons	102,596 tons	

Dredging Rates and Timing

% solids produced by dredge = **8.0%**
Hourly Production (one dredge, full efficiency) = **80** in situ cy/h
Number of dredges = **1**
Dredge efficiency = **50.0%**
Dredge Removal Rate = 960 in situ CY/d requiring 112 dredge days 22.3 weeks, with **5** dredge days per wk
0.524 MGD pumpage
728 gpm per dredge during active dredging
184 dry tons/d
2,297 wet tons/d

Desanding

sand stream sand specific gravity = **2.65**

assumes same time frame as dredging

Scenario	Sand Separation (% dry wt.)	% solids after drainage	Sand Stream (wet tons/d)	Sand Stream (wet tons)	Saturation Ratio (Vw/Vv)	Sand Porosity	Bulk Density (t/cy)	Sand Volume (CY)
1	**0%**	**85%**	0	0	**0.60**	0.44	1.48	0
2	**0%**	**85%**	0	0	**0.60**	0.44	1.48	0
3	**0%**	**85%**	0	0	**0.60**	0.44	1.48	0
4	**0%**	**85%**	0	0	**0.60**	0.44	1.48	0
5	**0%**	**85%**	0	0	**0.60**	0.44	1.48	0

Rapid Dewatering of Desanded Sediment and Water Treatment Loading from Rapid Dewatering

assumes same time frame as dredging
assumes saturation of sediment

Scenario	Desanded Stream Loading to Dewatering: Mass Loading (wet tons/d)	Specific Gravity (adjusted)	Transfer % solids	Conditions for initial dewatering: Dewatered Fines % solids	Dewatered Fines (wet tons/d)	Dewatered Fines (CY/d)	Dewatered Fines (wet tons)	Dewatered Fines (CY)	Bulk Density (t / CY)	Water Treatment (MGD)
1	2,297	2.50	8.0%	**38%**	484	443	53,998	49,482	1.09	0.43
2	2,297	2.50	8.0%	**33%**	557	530	62,179	59,193	1.05	0.42
3	2,297	2.50	8.0%	**27%**	681	677	75,997	75,594	1.01	0.39
4	2,297	2.50	8.0%	**22%**	835	861	93,269	96,096	0.97	0.35
5	2,297	2.50	8.0%	**30%**	613	596	68,397	66,574	1.03	0.40

L-3

Geotextile Strength Calculations

Geotextile Strength Calculations

1. Purpose

Evaluate the strength properties of the geotextile cushion used in the dewatering pad.

Given

A 6 oz/yd^2 geotextile will be placed above the 30-mil PVC liner for protection

- Maximum leachate stone size ~ ¾", ,average stone size ~ 3/8" (ASTM C-33, No 6)
- Assume maximum truck tire pressure ~ 100 psi

Analysis

Evaluate the geotextile strength for the following conditions:

1. Burst resistance
2. Tensile strength
3. Tear resistance

1) Burst Resistance

Using extreme 100 psi tire pressure at geotextile interface, required burst resistance using a factor of safety of 3 is:

$$F.S. = \frac{3.6 * Ptest}{d_a * 100}$$ (Koerner, Designing with Geosynthetics)

where: F.S. = factor of safety = 3
Ptest = the burst test pressure
d_a = the average stone diameter = 3/8"

From attached Reference No. 1, the required burst strength is **25 lb/in^2**.

From Reference 2, a 6 oz/yd^2 (Amoco Geotex 601) has a burst strength of 280 psi > 25 psi

F. S. allowable = 280/25 = 11.2; therefore, burst strength is acceptable

2) Tensile strength

Where:

$$T = p'(\gamma)^2 \text{ (Koerner, Designing with Geosynthetics)}$$

T = mobilized tensile force
p' = applied pressure
γ = Geotextile strain

Assume 100 psi truck tire pressure on stone base of 3/4" max.

From Reference No. 2, grab strength = 160 lb
Calculate the max strain assuming 50% slippage at the stone/geotextile interface

$$\textit{Where } \varepsilon = \frac{3(d/2)}{d+2(d/2)}(100\%)$$

$$\textit{for } d = 3/4" \ \varepsilon = \frac{3(0.75"/2)}{0.75"+2(0.75"/2)}(100\%) = 75\%$$

Assume 50% slippage

Then:

$T = (100)\ (0.375)^2 = 14.1$ lb

F.S. = 160/14.1 = 11.4; therefore, tensile strength is acceptable

3) Tear Resistance

Where:

$$Treq = (\pi\ da^2\ p^1)\ s^1 \text{ (Koerner, Designing with Geosynthetics)}$$

da = average diameter of stone = 0.375"
p^1 = contact pressure (assume 100% of tire pressure) = 100 psi
S^1 = shape factor = 0.4 (crushed rock) (Koerner, Designing with Geosynthetics p 166)

$$Treq = (\pi\ 0.375^2 \text{ x } 100 \text{ lb/in}^2)\ 0.4$$
$$Treq = 17.7 \text{ lb}$$

From fabric chart, Reference No. 2
Puncture strength = 85 lb

F.S. = 85/17.7 = 4.8; therefore tear resistance is acceptable.

Conclusion

A summary of the strength calculations for a 6 oz/yd^2 geotextile is presented below:

Analysis	Calculated F.S.
Burst Resistance	11.2
Tensile Resistance	11.4
Tear Resistance	4.8

Based upon results of the analysis, the proposed 6 oz/yd^2 geotextile will provide adequate protection for the underlying geomembrane liner.

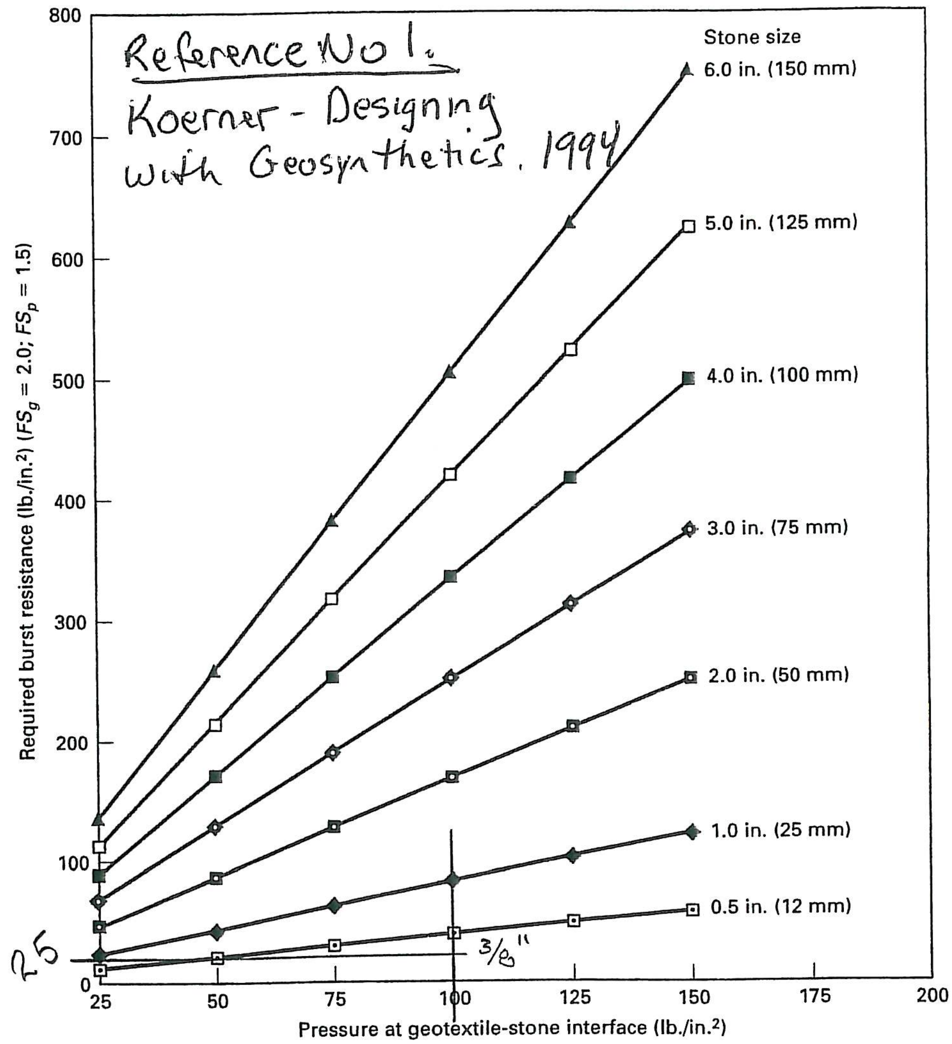

Figure 2.27 Design guide for burst analysis of geotextile used in a separation function based on a cumulative partial factor of safety of 1.5 and a global factor of safety of 2.0 (i.e., a total factor of safety of 3.0).

Reference No. 2

PRODUCT DATA SHEET

GEOTEX® 601

GEOTEX 601 is a polypropylene, staple fiber, needlepunched nonwoven geotextile produced by Propex, and will meet the following Minimum Average Roll Values (MARV) when tested in accordance with the methods listed below. The fibers are needled to form a stable network that retains dimensional stability relative to each other. The geotextile is resistant to ultraviolet degradation and to biological and chemical environments normally found in soils.

GEOTEX 601 conforms to the property values listed below.[1] Propex performs internal Manufacturing Quality Control (MQC) tests that have been accredited by the Geosynthetic Accreditation Institute - Laboratory Accreditation Program (GAI-LAP).

		MARV[2]	
PROPERTY	TEST METHOD	ENGLISH	METRIC
Mechanical			
Tensile Strength (Grab)	ASTM D-4632	160 lbs	712 N
Elongation	ASTM D-4632	50%	50%
Puncture	ASTM D-4833	85 lbs	378 N
CBR Puncture	ASTM D-6241	410 lbs	1824 N
Mullen Burst	ASTM D-3786	280 psi	1930 kPa
Trapezoidal Tear	ASTM D-4533	60 lbs	267 N
Endurance			
UV Resistance	ASTM D-4355	70%	70%
Hydraulic			
Apparent Opening Size (AOS)[3]	ASTM D-4751	70 US Std. Sieve	0.212 mm
Permittivity	ASTM D-4491	1.30 sec^{-1}	1.30 sec^{-1}
Water Flow Rate	ASTM D-4491	110 gpm/ft^2	4480 $l/min/m^2$
Roll Sizes		12.5 ft x 360 ft 15 ft x 300 ft	3.81 m x 109.8 m 4.57 m x 91.5 m

NOTES:

1. The property values listed above are effective 08/2006 and are subject to change without notice.
2. Values shown are in weaker principal direction. Minimum average roll values (MARV) are calculated as the typical minus two standard deviations. Statistically, it yields a 97.7% degree of confidence that any samples taken from quality assurance testing will exceed the value reported.
3. Maximum average roll value.

PROPEX | THE ADVANTAGE CREATORS.℠
GEOSYNTHETICS

Propex Inc.
6025 Lee Highway, Suite 425
PO Box 22788
Chattanooga, TN 37422

PH: 423 899 0444
PH: 800 621 1273
FAX: 423 899 7619
www.geotextile.com

L-4

Geotextile Dewatering Tube Sizing Calculations

Scope

Evaluate geotextile tube drainage capacity as per Dewatering Technical Standard 1061

Condition

Dewatering of the Nagawicka Lake sediments will be performed by geotextile tubes placed within a lined 200,000 square foot dewatering pad. Carriage water from the dredge areas will be pumped into the geotextile tubes. Sediments will be contained within the tubes, while decant water will flow out of the tubes, into the decant water collection system.

Calculations and Design

Section C of the standard provides guidance on the use of geotextile tubes. In addition to sizing geotextile tubes for particle size and flow rate, they should be sized with a 50% clogging factor. They should also meet the criteria in Table 1 of Section C, as shown below.

Table 1
WDNR Technical Standard 1061 - Properties for Geotextile Materials.

Property	Test Method	Type I Value	Type II Value
Maximum Apparent Opening Sizes	ASTM D-4751	0.212 mm	0.212 mm
Grab Tensile Strength	ASTM D-4632	200 lbs	300 lbs
Mullen Burst	ASTM D-3786	350 psi	580 psi
Permeability	ASTM D-4491	0.28 cm/sec	0.2 cm/sec
Fabric	Nominal Representative Weight	8 oz	12 oz

- In addition to WDNR Technical Standard 1061, geotextile literature was reviewed for expected permeabilities. This material, or equal, will be selected for use for the dewatering geotextile tubes.

- Flow rate through the geotextile tubes is determined using Darcy's Law:

$$Q = K * I * A \qquad (1)$$

where
- Q = flow rate (ft^3)
- K = hydraulic conductivity (ft/day)
- I = hydraulic gradient (ft/ft)
- A = area available for flow (ft^2)

Clogging of the geotextile material was considered at 50% in calculating the flow through the tubes. The gradient (I) in equation 1 is taken as the land slope of the dewatering pad, which is 1.0% (0.01 ft/ft).

The wetted perimeter area of the tubes is 7,200 sf (60-foot circumference by 120 feet long). Flow rate through the tubes is then found using equation 1:

$$Q = K * I * A$$
$$Q = (0.28 \text{ cm/sec} * 1 \text{ ft}/30.48 \text{ cm}) * 0.01 \text{ ft/ft} * 7{,}200 \text{ sf}$$
$$= 0.661 \text{ ft}^3\text{/sec} * 7.48 \text{ gal/ ft}^3 * 60 \text{ sec/min} = 296.7 \text{ gpm} * 1440 \text{ min/day}$$

= **427,248 gpd**

= **213,624 gpd @ 50% clogging**

As a conservative measure, water lost to evaporation was not included in these calculations.

Conclusions

Geotextile material specifications were reviewed and the dewatering tube was evaluated for expected flow through the geotextile. A geotextile material with a permeability of 0.28 cm/sec was selected. A geotextile dewatering tube constructed of the aforementioned material with dimensions of 60-foot circumference by 120 ft total length gives a total maximum flow rate of 213,624 gpd or 148 gpm, assuming a clogging rate of 50%.

The sediment process calculations indicate that the dredging operation will pump an average of approximately 730 gpm of sediment laden slurry to the dewatering facility. Calculations to determine the number of geotextile tubes indicate approximately 89 tubes will be needed for this project. During active dredging, the Contractor will be required to direct sediment into multiple tubes concurrently, as determined by the dredging quantity.

References

Wisconsin Department of Natural Resources, 2007. Dewatering Standard (1061).