ATTACHMENT 3

October 30, 2012

Enbridge Energy Company Inc.,
333 South Kalamazoo Ave,
Marshall MI, 49068

Attention: Mr. John Sobojinski

RE: Winter 2012/2013 Containment in the Kalamazoo River

The following is SWAT Consulting Inc.'s (SWAT's) general comments regarding the installation of containment strategies in the Kalamazoo River during the winter of 2012/2013. This information is based on experiences, challenges and general site knowledge and includes data gathered while completing containment installation within moving and stagnant water bodies over the past 22 years on over 650 releases. Over 200 of these releases occurred during winter conditions.

ICE CHARACTERISTICS

There are numerous types of ice present in natural water ways, the basic types are border ice, sheet ice and frazil ice.

Sheet ice or thermally grown ice is typically located in low flow or stagnant areas. Sheet ice formation initiates from the shoreline areas (border ice) and extends horizontally into the water body. The thickness of sheet ice can vary, dependent on ambient temperatures, water temperatures, rate of flow, exposure to direct sunlight and numerous other factors. The stability of sheet is dependent on water levels, consistency of ambient temperatures and flow rates. Fluctuations of water levels in excess of 4-6 inches can cause the breaking and possible dislodging of the sheet ice from shoreline areas. If water flow is present, this ice can be forced downstream. Manmade disturbances such as boat traffic can also cause sheet ice to become unstable.

Frazil ice is created during sudden periods of intense cold where surface waters become supercooled (just below freezing) when little to no ice cover (insulating layer) is present. Strong winds during these intense cold periods can also contribute to frazil ice creation. This type of ice formation is usually present in areas where turbulent water is present. This turbulence can be caused by rapids, wave action from wind or from obstructions. Frazil ice formation can occur at any water depth, depending on the water turbulence and can adhere to the river bed or submerged obstructions as well as the bottom of sheet ice. In areas of restricted flow, accumulations of this sort can lead to the creation of ice jams. Accumulations of frazil ice against a structure can exert extreme forces due to the weight of the ice that continues to increase as the ice accumulates.

IMPACTS ON FLOW PATTERNS

Dependent on ice thickness, water flow is redistributed vertically due to the decrease in the channels flow capacity. As the ice thickness increases (due to freezing or ice buildup, ie: Ice Jam), the flow rate throughout the water column increases, this is especially prevalent in areas where the flow rate is lower therefore increasing the rate of freezing and ice thickness. Dam impoundments are susceptible to this condition due the reduction in flow velocity and increase in surface ice cover (ie: Ceresco Dam, Mill Pond area, Morrow Lake). This increased flow rate will impact the effectiveness and survivability of any structure present within the water column.

ICE JAMS

The creation of ice jams are very difficult to predict. Temperature fluctuations, severe increases and decreases in temperature all contribute to the initiation of ice jams. In stream obstructions such as culverts, narrow channels, shallow areas, bridge pillars or anywhere that the channel is constricted can potentially initiate ice jam formation.

As ice (typically sheet or frazil ice) migrates downstream it will continue to accumulate and stack on an obstruction and dependent on numerous conditions, could cause an upstream backup affect that extends for miles.

The release of ice jams can occur in a slow manner over a long period of time or violently over a very short time period. The sudden release of an ice jam could be devastating to downstream users. Downstream impacts during a fast release are common and can be life threatening, may cause extensive flooding and possible destruction of property.

Backwater impacts as a result of an ice jam can be significant with flow patterns changing and even being redirected to areas where flow typically does not occur. Depending on the stacking of the ice, location of the dense ice accumulations and substrate type, there is the potential for increased bottom scouring and subsequent altering of channel characteristics. Extreme events have been known to completely change the course of rivers whereas a new channel is created.

HISTORICAL CONDITIONS (Winter 2010/2011)

Between the dates of December 12 and December 14, 2010, ambient temperatures in the Marshall/Battle Creek/Kalamazoo areas dropped from 37 to 11 degrees Fahrenheit (F). Wind gusts during that period ranged from 20 to 35 mph.

As a result of the rapid decrease in ambient temperature frazil ice was created throughout the majority of the river system between Marshall and Morrow Lake. This frazil ice accumulated at numerous locations (upstream of Ceresco Dam, upstream of Dickman Road in Battle Creek as well as between the 35th Street Bridge and Morrow Lake). The results of this frazil ice creation and movement was the failure of the 35th Street Bridge surface/subsurface containment site as well as the creation of an ice jam at MP 15.5.

At Ceresco Dam the majority of the frazil ice accumulated on the surface waters up to the Milepost 4.75 marker where it froze in place due to the reduced flow rates resulting from the Ceresco impoundment. On December 13 and 14, 2010, subsurface frazil ice was present and visually observed migrating downstream immediately upstream of the Ceresco Dam outflow. This frazil ice movement was visually evident along the river bottom.

At the Dickman Road culverts in Battle Creek (MP 15.50), frazil ice buildup occurred as far upstream as MP 12.75 over a period of 4 days. As a result of this frazil ice buildup and the small ice jam created against Dickman Road, upstream flooding occurred as far upstream as MP 13.0, encroaching on a work site and flooding an agricultural field.

At the Morrow Lake Delta, frazil ice buildup was present from the E4 location (MP 37.75) to MP 36.25. This frazil ice accumulation resulted in the destruction of the 35th Street Bridge containment location. The containment at this site consisted of a surface hard boom and subsurface curtain combination. The containment site was broken into 3 pieces with portions of the system migrating over 1000’ downstream before crews could be mobilized to the site to complete the extraction of the materials.

HISTORICAL CONDITIONS (Winter 2011/2012)

Due to the mild winter conditions, no significant ice accumulation or movement occurred during this period. Numerous high flow events did occur as a result of the continuous freeze/thaw and precipitation that occurred throughout this winter. On December 7, 2011 water flows at the USGS Kalamazoo gauge in Battle Creek reached 2100 cfs. On March 4, 2011 flows reached 2250 cfs.

NAVIGATIONAL HAZARDS

The installation of any structure within navigable water ways requires the use of navigational markers/aids in order to identify the structures so that water course users are aware of the presence of a known hazard. Improper marking or identification of a known man made structure would pose significant liability on the responsible party in the event of an incident.

The use of surface floating buoys (both colored and lighted) anchored to the river bottom are typically utilized for the purpose of identifying installed structures. During the winter conditions, the survivability of floating buoys in flowing water bodies is significantly reduced. The presence of floating ice, both frazil and sheet ice, can damage or destroy the floating buoy. During normal freezing conditions, floating buoys will become frozen in surface ice. In flowing water bodies, the release and movement of this surface ice is inevitable and may cause dislodging of the anchor system attached to the surface buoy. The potential downstream migration of this anchor system could cause significant damage to any structures and could also initiate the creation of a localized ice jam.

CURRENT E4 CONTAINMENT SYSTEM

The current containment system located in the Morrow Lake delta and neck consists of anchor posts, floatation boom (high tension cable, foam floatation, PVC outer coating, ballast chain and ASTM universal connectors), ½ curtains (with internally woven ballast chain) and strapping connecting the floatation boom to the ½ curtain. The system can be easily adjusted to compensate for fluctuating water levels by utilizing the strapping system that is connected to the surface boom (dependent on water depth).

Reconfiguration of the existing system to a new anchor or suspension style would require complete removal and reconfiguration of the entire system.

This system was designed to withstand low to moderate flows of the Kalamazoo River and was intended to be removed prior to icing conditions. The maximum flow that they system is expected to withstand is estimated to be no greater than 2000cfs, although as per Michigan Department of Environmental Quality Permit No. 12-39-0027-P, the release of the containments system is far below that value. As a result of the critical structure located approximately 1.5 miles upstream of the E4 system, a water elevation at that location of 777.5 feet amsl, requires complete release of the containment system.

The system is not designed to withstand any significant floating material such as ice or large timber (sometimes present during spring break up).

MAINTENANCE

Maintenance on any type of submerged containment system during the winter/frozen months is a critical safety concern. The unstable condition of most ice on a moving water body creates numerous safety issues. The use of airboats can aid in navigation but only if smooth surface ice is present, any jagged or uneven ice surfaces will severely hinder the maneuvering ability of an airboat.

Completing in water adjustments of any containment system with ice cover preset is extremely difficult due to visibility issues as well as the potential movement of surface ice.

ADDITIONAL CONSIDERATIONS

The installation of a subsurface containment structure will affect the displacement of water, especially when combined with surface ice. The use of a subsurface obstruction during frozen conditions will severely reduce the available discharge area thus causing an increase in water velocity below the ice surface. This action will create additional strain on the containment system and could cause a complete failure of the system.

A critical failure of a submerged containment system during winter conditions could cause significant adverse effects to downstream areas. The possibility of river bottom scouring is also a concern. Rapid increases in backup effects could occur due to increased ice thickness and potential frazil ice accumulation, not only on the bottom of the water body but also under the ice surface. In the event of a failure, increased velocities at the river bottom could amplify the erosion and increase sediment flow. With increased velocities there is also the potential for ice heaving and breakup throughout downstream areas (within the lake impoundment).

The river is currently open for public use and during the winter months, ice fishing will be an activity that local residents will most likely participate in. If a catastrophic failure was to occur, the impacts to these recreational users could be severe.

CONCLUSIONS

Based on the known presence of frazil ice throughout the Kalamazoo River during most winters, the potential creation of an ice jam, the safety of workers, the limitations of the available containment systems and the navigational hazards resulting from the installation of any subsurface structure, it is recommended by SWAT that no containment structures be installed during the winter months.

The unpredictability of adverse weather conditions and the unknown risks of the installation of a surface or subsurface structure pose uncontrollable safety concerns for the workers as well as potentially severe impacts to local residents and river users.

The most effective form of containment for mobile sediment is water retention. Retention time allows for the settling of sediment present within the water column, the longer the area of retention, the more effective it becomes. The most effective way to create water retention is a Dam, in this situation, the presence of a dam already exists at the west end of Morrow Lake. The presence of Morrow Dam creates a backup effect that extends to the upper reaches of the delta, whereby sediment deposition occurs throughout the delta, neck and fan of Morrow Lake.

SWAT has completed surface and subsurface containment of this nature in water courses similar to the Kalamazoo River in the past. In areas where lesser flows are present, the containment systems have been successful; the installation of these systems was also completed in remote areas, where the creation of backup effects, ice jams and potential flooding were not a concern. It has also been documented that during peak periods of high flow, barriers along the bottom substrate within a water course may cause extensive erosion and eventual failure. Skirting or curtain systems are especially susceptible to this condition due to the method of adherence to the rivers bottom, ie: ballast chain.

Other methods of subsurface containment are available and have been explored, but the same risks as noted above apply. There is no guarantee that the creation of an ice jam and the subsequent hazards will not occur with the installation of any obstruction within a flowing water body.

CLOSURE

The information provided is representative of the general environmental conditions at the site.

The material contained within reflects SWAT's opinion of the conditions at the site from the information available to SWAT at the time of writing the document.

Any use which third party make of this proposal or any reliance on, or decisions based on the information contained within, are the responsibility of such parties. SWAT will not be held responsible or liable for any damages to the physical environment, any property, or to life, which may occur from the actions or decisions based upon any of the information within.

I trust everything is in order; should you have any questions or concerns, please contact the undersigned at [redacted] at your earliest convenience.

Dean S

SWAT Consulting Inc.
Dean Sahara – Release Coordinator
Trever Miller – Release Coordinator

REFERENCES

Daly, S. F. (1994, August). Report on Frazil Ice. *International Association for Hydraulic Research Working Group on Thermal Regimes.* US Army Corps of Engineers, Cold Regions Research & Engineering Laboratory.

Ashton, G. D (1986). *River and Lake Ice Engineering*. Littleton, Colorado: Water Resources Publications.

Daly, S. F. (1991, March). Frazil Ice Blockage of Intake Trash Racks. *Cold Regions Technical Digest*, No. 91-1. Retrieved October 26, 2012, from http://www.crrel.usace.army.mil/library/technicaldigests/CRTD91_01.pdf

CONTAINMENT REPORT
WINTER 2012

1. EVALUATION OF PUBLISHED REFERENCED MATERIALS RELATED TO WINTER CONTAINMENT

1.1 CONTAINMENT REFERENCED MATERIALS

- Illinois Urban Manual Practice Standard Dated April 2010 Page 836-4 "Ice and floating debris pose a potential for damage to the silt curtain. Floating debris should be removed immediately when it poses a threat to the silt curtain. Silt curtains are not recommended for use during the winter months, especially when freezing conditions are expected"
- Earthwork within Lakes and Ponds March 31, 2012 Page 49 "They should not typically be left in place during winter"
- Statewide Urban Design and Specifications October 18, 2011 Section 7E-24 "Sediment curtains should not be left in place during winter months, as ice can cause the curtain to rip or torn from its shoreline supports"
- Science Applications International Corporation Section 6.4 Page 7 "The effectiveness of silt curtains is reduced under the following conditions: Drifting debris and/or ice"
- City of Kelowna, British Columbia BMP, July 21, 1998 Page 3 Of 18 "Strong currents, waves, ice, floating debris and boats can damage or destroy silt barriers"
- Maine DEP, Bangor Landing April 27, 2012 Page 11 "Silt curtain trapped ice, ice flow tore at curtain"
- Ontario Canada BMP – 2005 Page BMP 32-1 Turbidity Curtains, Limitations. "Not feasible in higher currents (greater than 0.5 meter per second), Not feasible in higher or breaking wave conditions, Not feasible in the presence of ice"
- EPA-GLNPO, Assessment and Remediation of Contaminated Sediments Program 10/10/03 Page 8 of 12 "Conditions that will reduce the effectiveness of barriers include: Strong currents, high winds, excessive wave height, drifting ice and debris"

2. EXPERT EVALUATION OF WINTER 2012/2013 CONTAINMENT IN THE KALAMAZOO RIVER

2.1 SEE ATTACHED LETTER DATED OCTOBER 30, 2012

2.2 SEE ATTACHED MEMORANDUM DATED AUGUST 28, 2012

3. EVALUATION OF THE WESTON TECHNICAL MEMORANDUM-Proposed Containment Systems through Winter 2012

3.1 DISCUSSION OF PROPOSED CONTAINMENT STRUCTURES PRESENTED IN FIGURES 4 THROUGH 8

- The proposed containment contemplated in figures 4 through 8 are conceptually similar and share similar risks. These risks are discussed in the following section:

- The proposed structures create a submerged water navigation hazard. The buoys cannot be used to identify the hazard during winter conditions. Ice movement will dislodge the buoy anchors in flowing areas. Severe injury/death could result if a powered vessel struck the submerged cable without knowing of its presence. It is not practical to mark the submerged structure well enough to ensure that river users will be aware of its presence.

- The proposed structures also increase the potential of an ice jam. Ice jams can cause flooding to upstream and downstream areas. Sudden release of an ice jam can have severe consequences. Surface ice thickness could exceed the 1' that is proposed for cable depth. Morrow Lake/Delta/Neck ice thickness has exceeded 12" in recent years and up to 24" + based on local residents comments.

- The proposed structures could fail due to Frazil ice movement. Frazil ice buildup at Battle Creek in 2010 exceeded 24" in thickness. Freezing of the cable into the surface ice will destroy the containment system if the ice shifts/fractures or breaks up in flowing areas.

- Very high potential exists for Frazil ice movement on the water surface as well as subsurface, as seen on numerous occasions in the winter of 2010/2011

- High flows during a "mild" winter could cause failure of the proposed structures. Increased flows exceeding 1120 cfs will force the removal of the entire containment system as required in the MDEQ permit. Flows during the winter of 2011/2012 exceeded 2100 cfs on two occasions. Flows this high create a high potential for large debris movement. Large debris will become entangled with the containment system and could cause system failure.

- The proposed structures would create maintenance difficulties in the event that the system survives ice in. Inspection and maintenance would be a serious safety issue during frozen conditions due to unstable ice.

- If the proposed structures become damaged and dislodged as a result of ice movement there is a chance that they will migrate downstream with the ice. Similar to the 35th Street X-Tex in 2010, any submerged curtain has the chance to collect Frazil ice. As the ice builds up on the front side of the curtain it is possible that the curtain will become damaged due to the severe weight and force of the built up ice. The system could become entangled in downstream areas such as a Dam, hydroelectric turbines, and culverts. The potential blockage created by a dislodged containment system could create a significant ice jam.

- Due to the time of the year, installation of these proposed structures could not occur prior to winter. Additionally permitting timelines will not likely allow placement prior to ice up.

- The cable referred to in figure 4 is currently attached to the existing hard boom. Removal of this cable while attached to the hard boom is not possible. The existing curtain is connected to the ballast chain rather than the high tension cable for most of the deployment. Angles suggested on the cables at the shoreline anchor points are extreme and will cause significant stress on the cables. Due to the tension requirements on the suspension cables, stronger posts would be required, possibly I beams. Heavy equipment would be required for installation. Previously used construction methods would not be feasible. Reattaching the cable in a fixed position as shown in figure 4 would likely result in regular ice contact as water level drops during the winter. The design does not allow adjustment of the curtain because it will be 2' below the water surface and out of reach from a boat. In addition, there is no safe quick release option if the system causes a back water effect.

- The existing anchor systems were not designed to hold the tension that would be required to keep a cable suspended over the required span. Figure 8 is an anchor installed into disturbed ground. Due to the ground disturbance and the shallowness of the anchor, this will not hold when extreme tension is placed on the anchor.

- Landowner access and MDEQ approvals will be required for all aspects of the installations.

- Monitoring the proposed structures will be problematic as ice forms. Therefore, ice in moving water is unpredictable, making inspection unsafe.

3.2 DISCUSSION OF THE CABLE STAYS DESCRIBED IN FIGURE 5

- The buoys are in the zone which is labeled in the legend as ice zone; this installation would likely fail due to ice movement.

- The Screw anchors would add increased installation time with having to set the anchors all at the same elevation. This would be extremely difficult because some areas have an excess of two feet of soft sediment and some areas have a hard gravel bottom.

3.3 COIR LOG ALTERNATIVE PRESENT IN FIGURE 9

- The design presented in figure 9 will also have risks similar to the alternatives presented in figures 4 through 8 noted above. In addition, this alternative also has some specific risk such as:

    - Once coir logs become saturated with water they become extremely brittle and due to the weight when saturated, become extremely difficult to handle/move. The coir logs are bio degradable and will fall apart once their life expectancy is reached.

    - Extensive staking (quadruple at minimum) would be required to keep the logs submerged in flowing water. Installation in areas where soft sediment is present could result in inadequate anchoring using staking techniques.

- Release of this system, due to backwater effects, will be problematic because of surface ice.

  High flows could create an extreme amount of scouring due to its relatively low permeability.

3.4 DISCUSSION OF THE CONTAINMENT SYSTEMS PRESENT IN FIGURES 10 AND 11

- The designs presented in figures 10 and 11 will also have risks similar to the alternative presented in figures 4 through 8. In addition, these alternatives will have specific risks such as:
- With the top edge of the curtain not secured, it will sag in the current.
- Scouring will occur around Jersey Barriers and Gabions.
- The curtain will not be adjustable.
- Installation of these systems will require professional divers and heavy equipment.
- Digging in the Jersey Barriers would create significant turbidity especially in flowing areas.
- Uncontrollable erosion would also occur.
- Several safety hazards to river users, such as boaters, fisherman, etc.

4. EXISTING E4 CONTAINMENT

4.1 EFFECTIVENESS

- Based on current conditions, the monitoring completed over the past three months and the visuals inspections of the curtain/ballast chain, the primary objective of maintaining an effective seal between the curtains ballast chain and the river bottom was achieved.
- Field observations indicate sediment removal will not be required prior to curtain removal. An inspection of the entire system conducted in late October 2012, including probing/poling of the ballast chain at the base of the curtain, no significant buildup of sediment was observed at any location. Subsurface video of the curtain shows the ballast chain remains on the bottom at all locations and appears to be functioning as designed.

4.2 REMOVAL RATIONAL

- This configuration was designed to be removed prior to ice formation/flow within the river system. Any amount of ice movement/buildup within the flowing sections of the river will cause significant damage and possible "tear out" of the containment system.

- The designed configuration for flows was less than 2000 cfs. Flows exceeding this rate may cause damage to the curtain and may impact the containment ability of the system. During the winter of 2011/2012, flows exceeded 2000cfs on two occasions.
- Significant ice movement in the area around the system would likely result in catastrophic failure of the system.
- Creation of an ice jam in this area poses severe downstream safety issues and possible back water effects.
- Maintenance of this system during frozen conditions creates safety hazards, during periodic adjustments in the ½ curtain due to water level fluctuations.

4.3. CONSIDERATIONS DURING REMOVAL

- Curtain removal should be from the top down, utilizing the downstream segment as containment during removal. Therefore, additional downstream containment during removal will likely not be required, but turbidity monitoring during removal should be conducted.

5. CONTAINMENT ALTERNATIVES FOR FURTHER EVALUATION

An evaluation of alternatives in non-flowing river sections as well as flowing sections is present below.

5.1 CONTAINMENT IN NON-FLOWING RIVER SECTIONS

- Surface containment boom and subsurface curtain (in non-flowing portions of the river where ice buildup is not present) may survive ice buildup within the main channel and could be used in oxbows, back channels, slow moving or stagnant areas out of the main flow, depending on the severity of the ice up of the river.
- This system was used in 2010 in non-flowing areas where shoreline or overbank impact was known.

5.2 ALTERNATIVES FOR FLOWING RIVER SECTION

- Depending on where sheet piling is placed (there are limitations to the vertical penetration due to known bedrock at shallow depths) this method of containment will be hampered by ice movement and bedrock depth. However, potential ice movement would put significant stress on the outer sections of sheet piling.
- In areas upstream of the trestle (MP 4.5-5.0) bedrock is known to be quite shallow, 3-4 feet of penetration may be the limit therefore the strength of the sheet piling would be questionable without even considering the increased potential for backwater flow and ice jams.
- Installation of sheet piling in the area of the Ceresco Impoundment (between the dam and the trestle) is problematic due to the presence of bedrock at a depth of 8-10 feet.

With normal flows this would require constant monitoring and maintenance. In addition, pounding or vibrating sheet piling in that area is a risk with regard to the integrity of the Dam.

5.3 JERSEY BARRIERS

- A wall of Jersey barriers could be installed by linking cable or chain. The barrier wall would be installed using a similar configuration with similar angles as surface boom.
- Subsurface scour can occur with jersey barriers, causing instability of this system.
- Jersey barriers will cause backup and affect the back water flood plain.

5.4 RIP RAP

- Placed on River/Lake bottom to create a barrier for creation of retention area on the upstream side.
- Removal of rip rap will cause damage to the river bottom and the MDEQ will not likely grant a permit for this alternative.
- Very low maintenance.
- Rip rap could withstand high flow events.

5.5 ICE BOOM

- Ice boom can be used in remote areas and very slow moving rivers or lakes, where ice jams are not a concern.
- Ice boom is durable and if anchored correctly can withstand significant ice buildup.

APPENDIX

A. Letter from Dean Sahara, President of SWAT Consulting, Inc. dated October 30, 2012

B. Memorandum from Bryan Rogne, AECOM titled Evaluation of Potential floodplain Impacts and Proposed Operational Modifications for Containment Near MP 37.50 dated August 28, 2012.

C. Published Reference Materials listed in 1.1, 98 pages

ILLINOIS URBAN MANUAL
PRACTICE STANDARD

SILT CURTAIN - FLOATING

(feet)
CODE 836

(Source: EPA Document Floating Silt Curtain Courtesy of Geofabrics Australasia)

DEFINITION

A temporary sediment control barrier consisting of a vertically suspended geosynthetic fabric installed within a body of water.

PURPOSE

The purpose of this practice is to provide sediment containment within a body of water for work in or near the body of water, as well as to deflect natural flow around the work area.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies to:

1. Construction activities in or beside a water body (river, stream, lake, pond, etc.)
2. Soil disturbance in or adjacent to a body of water
3. Bridge construction
4. In-stream or stream bank excavation
5. In-stream or stream bank fill
6. Stream bank revetment/erosion protection
7. Upslope ground disturbance near a body of water
8. Dredging
9. Construction runoff near water bodies
10. Protection of sensitive areas from sediment and turbidity
11. Streambank stabilization

CRITERIA

The maximum flow velocity of the body of water shall be 5 fps. For flow velocities greater than 5 fps, a specifically designed system shall be required.

The isolated area shall be the minimum necessary to complete the work and in no case shall encompass more than 1/3 of the total stream width. The silt curtain shall be installed so it will not be disturbed by the construction activities.

The silt curtain shall be placed parallel to or at an angle to the direction of flow, not perpendicular to the flow and shall not extend across an entire waterway with moving water.

The silt curtain shall extend the full depth of the water body except where significant wind or wave action is present (Type III below). The curtain depth shall be 10% longer than the water depth (at the anticipated high water level) for Type I and Type II applications to ensure the curtain rests on the bottom.

Where significant wind and/or wave action (over 1 foot) is present for the majority of the duration of the project, the depth of the silt curtain shall be 1 foot above the bottom at the mean low water level to prevent disturbing existing sediment on the bottom of the water body with the movement of the lower end of the silt curtain. Additionally, the maximum depth of the silt curtain where significant wind and/or wave action is present shall be 12 feet below the surface, regardless of the depth of the water body.

Both the top and the bottom of the silt curtain shall continue up onto the shore beyond the anticipated high water level. The bottom of the silt curtain shall be tapered to the shape of the shore. Furling straps may be used to adjust the length of the silt curtain up onto the shore.

<u>Types of silt curtains:</u>

The type of silt curtain selected shall be based on the average anticipated conditions.

Type I – no current, sheltered from wind and waves

Type II – moderate current (velocities up to 3.5 fps) and/or moderate wind and wave action

Type III – considerable current, high velocity (up to 5 fps), significant wind and wave action (over 1 foot) present

<u>Components</u> – The following components shall be used in the silt curtain, based on the anticipated conditions:

Fabric – The silt curtain shall be made from woven geotextile fabric meeting the requirements of material specification **592 GEOTEXTILE**, Table 1, Class 1. Within navigable waters, the fabric shall be a bright color (yellow or orange are recommended) to attract the attention of any boaters or swimmers.

The primary sediment type and particle size to be trapped shall be identified and the appropriate filter fabric requirements specified as shown in material specification **592 GEOTEXTILE**.

The fabric selection shall take into account the volume of water that must pass through based on the anticipated volume of water flowing into the protected area. The fabric selection shall also take into account the expected pollutant particle size based on the primary sediment identified.

The seams of the fabric shall be vulcanized welded or sewn and shall have the same strength characteristics as the fabric.

Floatation – Floatation segments shall be sealed into a sewn or heat welded seam along the entire top of the silt curtain to form a continuous float. Possible floatation material includes expanded polystyrene, ethafoam floats, or closed cell solid plastic foam floats.

Load Line – Type II and Type III silt curtains shall require a load line. The load line shall be a minimum ½" diameter rope installed in the sleeve within the floatation segments. The anchor shall be attached to the load line between the panels.

Ballast Chain – The base of the silt curtain shall be weighted to prevent it from billowing up and to maintain contact with the channel/pond bottom. A galvanized chain shall be sewn or heat sealed into a sleeve along the bottom edge. For Type I silt curtains the ballast chain shall weigh at least 0.7 lb/ft (1/4" chain). For Type II and III silt curtains the ballast chain shall weigh at least 1.1 lb/ft (5/16" chain).

Mooring – The silt curtain shall be properly anchored both onshore and in the water. The silt curtain shall extend up onto shore and be tied to a post or stable, large diameter tree (8" diameter or more at breast height).

For Type II and Type III installations, the anchoring system shall be designed based on the anticipated conditions (Type 1 installations do not require an anchoring system). The in-water anchor system shall consist of an anchor, chain, anchor line, buoy, crown buoy, and mooring cable – as needed (see Figure 1). The silt curtain shall be anchored every 100 feet at a minimum. For higher flow situations – where the current approaches 5 fps and/or waves over 1 foot are anticipated - the silt curtain shall be anchored every 50 feet. Silt curtains subject to reversing currents, waves, or flow from both sides shall be anchored on both sides.

The anchors shall be placed such that the slope of the anchor line is 7 horizontal to 1 vertical – this will minimize the stress on the silt curtain and increase the holding power of the anchor. A minimum ½" diameter rope shall be used for the anchor line.

The crown buoy shall be used to indicate the location of the anchor. Within navigable waters, the silt curtain and the anchor locations shall be clearly marked as they pose an obstacle to navigation.

Panel Connectors – Fabric panels shall have a minimum width of 50 feet. Adjacent panels shall be connected so as to provide a positive water seal and limit leakage using one of the following methods:

1. Sew the panels together using two stitch lines per seam and a stitch density of six to ten stitches per inch.
2. Join the panels of fabric using grommeted holes and rope lacing. The holes shall be only slightly larger than the rope to minimize leakage.
3. Use a slotted PVC pipe with evenly spaced gear clamps to connect the panels. Sew a ½" diameter rope into the ends of each panel and slide the ends of the panels down the slot in the PVC. The gear clamps shall be installed every 3 feet vertically and shall pass through a slot cut in each panel.
4. Use commercially available aluminum slide-connectors.

Various manufactured devices are available and the criteria established by the manufacturers of these products shall be included with the plans.

The silt curtain shall be installed from a boat, when feasible. The curtain shall be rolled around the bottom ballast chain and furled, or tied, together at the top. Once the silt curtain is in the proper location, the load lines shall be properly anchored onshore and anchors shall be installed in the water, as specified. The curtain shall be un-furled in place. The installer shall ensure the lower edge of the curtain is in contact with the bottom of the water body.

CONSIDERATIONS

Any work within a stream is subject to the rules and regulations of the U.S. Army Corps of Engineers for in-stream modifications. A permit may also be required from the Illinois Department of Natural Resources.

For Type I installations (still water with little or no flow into the containment area), the fabric can be relatively impermeable, creating a containment barrier. In general, however, silt curtains are not designed as water impoundment dams and should not be expected to stop the flow of a significant amount of water. The main purpose is to isolate the work area and allow sediment to settle out of suspension. If a dry work area is required within a body of water, see practice standards **COFFERDAM 803** and/or **DEWATERING 813**.

When a silt curtain is placed within a moving body of water, the constriction may increase the potential for erosion of the far bank. Erosion should be monitored regularly and corrected, as needed.

When a large amount of silt or other fine sediment is expected, the geotextile fabric may be selected to reduce the amount of flow through the silt curtain to allow for settlement. The fabric selection should take into account the amount of water flowing into the containment area as well as the anticipated flow conditions.

Additional length should be provided in the vertical height to accommodate the water level fluctuations during the life of the silt curtain. However, the silt curtain should not be too long or sediment will accumulate in the pleats on the bottom and may pull the silt curtain under the water.

Where construction activities are to take place next to a body of water, attempts should be made to maintain a vegetated buffer strip of sufficient width to trap sediment. See practice standard **BUFFER STRIP 801**.

Appropriately sized rip-rap or other weights that keep the curtain in contact with the bottom may be used in lieu of the ballast chain for Type I silt curtain applications.

Depending on the expected water conditions, additional slack may be needed in the curtain so rising and falling water elevations will not cause the silt curtain to become submerged.

When determining the type of silt curtain to use, the average anticipated wind speed should be considered. One exceptionally windy day over the course of a multi-week project may not warrant increasing the type. For longer duration projects, especially those in larger bodies of water, a contingency plan may be needed for extended periods of inclement weather.

When a silt curtain is used within navigable waters, the waves created by passing boats should be taken into consideration when selecting the appropriate type and anchoring methods. Also, a light buoy may be required to clearly identify the silt curtain.

When determining the overall length of the silt curtain, provide an additional 10 – 20% in straight line measurements for ease of installation, and to compensate for measuring errors, and to reduce stress on the barrier.

Ice and floating debris pose a potential for damage to the silt curtain. Floating debris should be removed immediately when it poses a threat to the silt curtain. Silt curtains are not recommended for use during the winter months, especially when freezing conditions are expected.

PLANS AND SPECIFICATIONS

Plans and specifications for installing silt curtain practices shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose. At a minimum include the following items:

1. Locations of silt curtain practices.
2. Type of silt curtain.
3. Filter fabric specifications.
4. Installation, removal and disposal directions, per manufacturers' specifications.

Refer to standard drawing ____.

All plans shall include the installation, inspection, and maintenance schedules with the responsible party identified.

If manufacturer's drawings are used, the designer shall verify that the requirements of this standard are met.

OPERATION AND MAINTENANCE

Each silt curtain practice or device shall be inspected on a daily basis at a minimum, using a boat where practical. The inspection shall check the condition of the floatation device, the fabric, load line, anchors, and buoys, as well as the location and functionality. Additionally, the bottom of the silt curtain shall be inspected for folds and accumulated silt, which may pull the silt curtain under the water.

Any necessary repairs shall be made immediately. Additionally, the silt curtain shall be inspected after each runoff event, as well as after heavy winds. Accumulated sediment shall be removed per manufacturers' directions but not less than when the capacity for sediment storage has been reduced by half. Sediment that has been removed shall be placed and stabilized such that it will not reenter the water body.

Repairs or replacement of devices shall be made immediately. Follow manufacturer's recommendations for fabric and material repair.

Allow sediment to settle a minimum of 24 hours prior to removing the silt curtain. Fine sediment may require longer settling time.

If clay and/or silt particles are present in the area protected by the silt curtain and won't settle out (or it is infeasible to wait for them to settle out), the water in the protected area can be pumped out. The protected area will slowly fill with water through the silt curtain. Once the water level has stabilized, the silt curtain can be carefully removed.

The accumulated sediment shall be removed by hand prior to removing the silt curtain. If equipment is used to remove the sediment, care shall be taken not to disturb the silt curtain. After removal of the accumulated sediment, sufficient time shall be allowed for re-settlement before removing the silt curtain. However, if is determined by the engineer and/or governing authority the removal of the sediment will cause more harm than leaving in the deposited sediment in place, carefully remove the silt curtain without disturbing the sediment.

The silt curtain shall be removed during calm weather and low flows. The silt curtain shall be removed by pulling it toward the construction area to minimize the release of trapped sediment. Both the top and bottom lines shall be pulled together like a parachute to pull the sediment ashore. Alternatively, the silt curtain may be furled and then removed, using a boat.

REFERENCES

Iowa State University. Center for Transportation Research and Education. Iowa Construction Site Erosion Control Manual, Chapter 3 – Structural Erosion Control Measures, 3.6 Flotation Silt Curtain. 2006.

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New York Standards and Specifications for Erosion and Sediment Control. Standard Specifications for Turbidity Curtain. August 2005.

City of Kelowna, British Columbia, Canada. Best Management Practices for Erosion & Sediment Control – Instream Works. July 21, 1998.

Francinques, N. R. and Palermo, M. R. (2005) "Silt Curtains as a Dredging Project Management Practice," DOER Technical Notes Collection (ERDC TN-DOER-21), US Army Engineering Research and Development Center, Vicksburg, MS.

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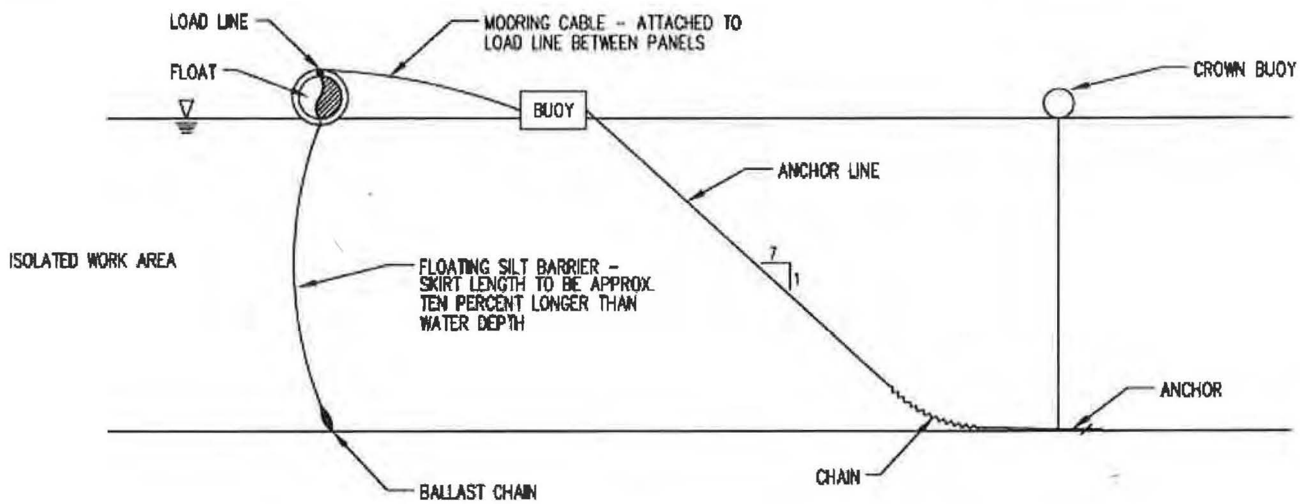

TYPICAL COMPONENTS / ANCHORAGE SYSTEM

Figure 1

US EPA ARCHIVE DOCUMENT

EARTHWORK WITHIN LAKES AND PONDS

NOTE: Wherever the structures described in this section are installed, the appropriate Chapter 105 permits must be obtained from the Department. Designs shall adhere to the conditions of those permits.

Since the water within a lake or pond typically has no appreciable flow velocity, a cofferdam is usually sufficient to protect impounded water from the turbidity caused by construction activity. Therefore, Figure 3.12 may be modified to provide a typical detail for such activity.

Turbidity Barrier (Silt Curtain)

A turbidity barrier is a heavy geosynthetic fabric suspended vertically in a body of water for the purpose of preventing sediment-laden water from escaping a work area and entering the main body of water. It is typically supported by a floatation system at the top and weighted at the bottom.

Geosol

A turbidity barrier is generally used where earthwork (e.g. dredging operations, streambank improvements, bridge pier construction, etc.) occurs within a water body, or along the shoreline, for relatively short periods of time, usually less than 1 month. It is most effective when used in calm water. Turbidity barriers should not generally be used where strong currents exist, and should never be placed across flowing watercourses. They should not typically be left in place during winter.

Design Considerations

- For ponds and other relatively still water bodies, the fabric should be relatively impermeable so as to provide a barrier between the clean water and the sediment-laden water. Runoff into this type of curtain should be minimized, due to limited available capacity.
- For moving water, such as in lakes and stream channels, provision should be made to allow passage of water through the curtain. This is normally done by constructing at least part of the curtain from a heavy filter fabric. While such curtains allow for some water movement through the curtain, the flow rate is low. Therefore, these curtains should not be installed across flowing watercourses. Turbidity barriers placed in stream channels should be placed parallel to the flow direction.

7E-24 Flotation Silt Curtain

BENEFITS

	L	M	H
Flow Control			
Erosion Control			
Sediment Control	■	■	
Runoff Reduction			
Flow Diversion			

Description: A flotation silt curtain (also called a turbidity curtain) consists of a geosynthetic fabric that is suspended vertically in a body of water. The top of the curtain is attached to floats, and the bottom is weighted.

Typical Uses: Flotation silt curtains are used when construction occurs in a water body or along a stream bank or shoreline. Flotation silt curtains prevent sediment, which is stirred up during construction, from migrating out of the work area and into the rest of the water body.

Advantages:

- Allows for containment of sediment-laden water within a water body.
- Protects contained water from turbulence, allowing particles to fall out of suspension.

Limitations:

- Limited to use only in areas where other erosion and sediment control practices cannot be used.
- Cannot stop the flow of a significant amount of water.
- Must not be used to filter entire stream flow.
- Difficult to remove fine silt and clay particles.

Longevity: One construction season (do not leave in place during winter).

SUDAS Specifications: Typically, flotation silt curtains are only used in special circumstances and therefore have not been included in SUDAS Specifications.

A. Description/uses

A flotation silt curtain, also called a turbidity curtain, consists of a heavy geosynthetic fabric that is suspended vertically in a water body, with floats at the top, and weights at the bottom. The purpose of the curtain is to act as a divider, preventing sediment laden-water from migrating to the rest of the water body.

Flotation silt curtains are commonly used when construction is required near or within a water body, where other erosion and sediment control practices cannot be used. This may include dredging operations, stream bank improvements, bridge pier construction, etc.

B. Design considerations

For ponds or other relatively still water bodies, which do not have significant inflow into the containment area, the flotation silt curtain consists of a relatively impermeable membrane that provides a barrier between clean water and sediment-laden water. The barrier creates a containment basin, in which sediment is trapped and allowed to fall out of suspension. Runoff into this type of curtain should be minimized, as the available volume is limited.

For situations that have moving water, such as lakes or streams, a provision must be made to allow water to flow through the curtain. This is normally accomplished by constructing part of the curtain from heavy filter fabric. The filter fabric allows water to pass through the curtain, maintaining equilibrium, but retaining sediment particles. While these curtains are designed to allow for some water movement, they do not have high flow-through rates, and should not be installed across a channel. When used in a stream, channel, or other body of moving water, the flotation silt curtains must be placed parallel to the direction of flow.

Unless the water body is subject to wind or wave actions, the curtain should extend the entire depth of the water, and rest on the bottom. The weighted bottom of the curtain needs to maintain contact with the bottom of the water body in order to keep sediment from flowing under the curtain. In order to do this, enough slack must be provided to allow the curtain to rise and fall as the depth of the water varies, without breaking contact with the bottom of the water body.

In situations where there is significant wind or wave action, the weighted end of the curtain should not extend to the bottom of the water body. Wind/wave action on the flotation system can cause movement of the lower end of the curtain, causing it to rub against the bottom, stirring up additional sediment. In these situations, a minimum 1-foot gap should be provided between the lower end of the curtain and the bottom of the water body. In addition, it is not practical to extend the curtain deeper than 10 or 12 feet. Deeper installations can be affected by the moving water, stressing the material, and causing the bottom of the curtain to be pushed around, billowing up toward the surface.

When determining the required length of the flotation silt curtain, an additional 10-20% should be included over the straight-line measurements. This allows for easier installation and reduces stresses caused by high winds and wave action.

Once the curtain has been positioned within the water body, the top is held in place by connecting it to anchors that are installed at regular intervals. The ends of the curtain (both upper and lower) should be extended to the shoreline, and anchored to a stable object, such as a tree.

C. Application

Flotation silt curtains are divided into three types, Type I, Type II, and Type III, based upon the flow conditions within the water body. The information provided here applies to minimal and moderate flow conditions, where the velocity of flow is 5 feet per second or less. For situations where the flow is greater than this, additional investigation is required, and a qualified manufacturer should be consulted.

The three types of silt curtains are differentiated by the strength and flow through rate of the fabric, and the strength of the connecting materials used:

1. Type I curtains are considered light-duty and are intended for areas where there is no current, and where the area is protected from wind and wave action.

2. Type II curtains can be used in areas with moderate running current (up to 3.5 fps), or where wind and water currents can affect the curtain.

3. Type III curtains are used in areas with considerable current (up to 5 fps), or where the curtain is subject to more severe wind and wave action.

D. Maintenance

A decision must be made on how to handle the accumulated sediment. Unless the accumulation is significant, consideration should be given to leaving this sediment in place. The process of removing the sediment can re-suspend the particles. Regardless of whether or not the accumulated sediment is removed, suspended sediment should always be allowed to settle for a minimum of 24 hours prior to removal of the silt curtain.

Once they are suspended in the water, clay and silt particles are difficult to remove by settling methods alone. For waters contaminated with clay or fine silts, the addition of a flocculent to the containment area may be considered prior to removal of the silt curtain. Care must be taken when selecting a flocculent as some are detrimental to water bodies and should not be used. See Section 7E-22 for additional information on flocculents.

E. Time of year

Sediment curtains should not be left in place during winter months, as ice can cause the curtain to rip or be torn from its shoreline supports.

6.4.3 Construction Equipment and Operational Controls

Several impact minimization measures involve methods associated with construction. These may include selection of certain types of equipment, operational controls, use of best management practices (BMPs), and/or modification of discharge locations. Many of the construction method minimization measures seek to reduce indirect impacts to biological resources associated with turbidity, entrainment, discharges, and/or noise. Examples of types of construction method mitigation measures are given below.

The review of water quality monitoring data in Section 5.5.3 suggests that contractors are effective in controlling the spatial extent of turbidity plumes. However, the specific effectiveness of any particular measure is difficult to evaluate because water quality reporting requirements do not require specification of what control measures were in place at the time monitoring measurements were collected, and few monitoring reports include that information.

6.4.3.1 Dredge Equipment Selection

Dredges vary in operational characteristics, which result in differences in suspended sediment plumes and concentrations (Sections 5.5.2). Generally, turbidity plumes and suspended sediment concentrations range from smallest to largest for the following types of dredge equipment:

- Cutterhead dredge, Hopper dredge without overflow, closed bucket dredge.
- Open clamshell bucket dredge, hopper dredge with overflow.

Dredge equipment has been modified to increase operational performance and/or effectiveness in minimizing environmental impacts. Use of closed buckets to reduce turbidity and use of larger bucket size to reduce duration of impact exposure are two of the more commonly referenced modifications, which are reviewed below.

Closed bucket dredge

Turbidity is minimized because there is less overflow spillage from closed bucket relative to conventional bucket dredges.

Relevant Reports:

- Turbidity levels up to 79% less than observed with a conventional bucket were reported for the Cable Arm closed bucket when dredging soft sediments (USACE 2001b cited in Anchor Environmental 2003).
- Analyses indicate that closed buckets may generate 30 to 70% less turbidity (Palermo and Pankow 1988 cited in Chambers Group 2001b).
- The effectiveness of a closed bucket may be reduced if air is trapped in the bucket at impact. Collins (1995) reported TSS concentrations of 150 mg/L with a closed bucket and 250 mg/L with a conventional bucket for one project. However, TSS concentrations were 150 mg/L for a closed bucket compared to 55 mg/L for a conventional bucket in another study. Air trapped in the bucket possibly contributed to greater bucket impact in the second study.

- Sediment type may influence effectiveness. Closed buckets have been reported to be ineffective and/or less effective at dredging consolidated material (Anchor 2001, Chambers Group 2001b).

Consideration of Potential Effectiveness:

The above noted report indicates a closed bucket is effective at reducing turbidity. Available reports indicate that turbidity plume extent and TSS concentrations generally are greater with a conventional bucket dredge than with a closed bucket dredge (Section 5.5.3.1).

<u>Bucket Size</u>

Bucket size may influence project schedule as a result of differences in sediment capacity. Bucket size also may influence generated turbidity as a result of differences in weight impacting the bottom.

Relevant Reports:

- Anchor Environmental (2003) reported that larger than normal dredges provide fewer disturbances due to less traffic and fewer dumps.
- Chambers Group (2001b) statistically determined that there was significantly less turbidity generated by a 10-cy bucket compared to a 14-cy bucket during the 1998 Marina del Rey, California maintenance dredging project (Chambers Group 2001). The small bucket released less water as it was raised through the water column. Chambers Group (2001b also considered that environmental impacts may be less in situations where larger buckets can remove more sediment per load than smaller buckets and reduce overall length of project schedule.
- Less sediment resuspension appears to result from small versus large bucket dredges (Collins 1995).

Consideration of Potential Effectiveness:

The effectiveness of bucket size as an impact minimization measure may vary depending on project and site specific environmental conditions. Some situations may favor selection of a small bucket, while others may favor a large bucket. For example, a small bucket may be preferred to reduce sediment resuspension near areas with sensitive resources. Use of a larger dredge may be effective in reducing overall impacts if the construction schedule is substantially shortened (e.g., weeks to days, months to weeks), but would not substantially minimize impacts if the project only realized a small incremental difference in construction duration (e.g., days).

6.4.3.2 <u>Dredging Operational Controls – Turbidity</u>

<u>Bucket Dredges</u>

Several factors contribute to sediment resuspension by bucket dredges, including sediment impact, penetration, and withdrawal, and loss of sediment during bucket ascent, removal from the water, and as the bucket is swung to the point of bucket release (Hayes et al. 1988, Collins 1995). Operational controls address each of those steps of bucket operation.

Relevant Reports:

The following operational controls have been reported for bucket dredges (LaSalle et al. 1991, Collins 1995, Chambers Group 2001, Anchor Environmental 2003):

- Slow the cycle time – This measure reduces the velocity of the bucket hitting the bottom and may reduce sediment wash out as the bucket is raised through the water column.
- Eliminate multiple bites – The practice of multiple bites involves repetitive lowering, raising, and reopening the bucket to obtain a fuller sediment load. Eliminating multiple bites reduces the number of times an impact wave of suspended sediment travels along the bottom away from the dredge and reduces sediment loss in the water column associated with reopening the dredge.
- Eliminate bottom stockpiling – Stockpiling of silty dredge material on the bottom increases sediment resuspension; therefore, restricting this practice may reduce suspended sediment concentration.
- Bucket Wash – Rinsing the bucket out at the barge to clean off excess sediment between loads may reduce sediment release in the water column.
- Waterline Pause – Briefly stopping the bucket at the waterline allows excess water to drain before raising the bucket from the water.

Consideration of Effectiveness:

The above-noted measures may be effective at reducing turbidity because they address limiting bottom disturbance, sediment resuspension, and sediment leakage and/or washout of the bucket. Some measures are more applicable to conventional than closed buckets, however, measures applicable to both include slowing the cycle time to reduce physical disturbance of the bottom and washing of the bucket. The applicability of both these methods likely depends on sediment characteristics and hydrodynamics in the project area; being more effective for fine sediments than sands. A potential disadvantage with slowing the cycle time may be an increase in project duration. Slowing the velocity of the bucket may reduce the volume of sediment obtained by the bucket during each bite (Chambers Group 2001, Anchor Environmental 2003).

<u>Cutterhead Dredges</u>

Sediment resuspension from a cutterhead dredge results when the suction does not keep pace with sediment agitation/slurry, resulting in sediment resuspension or release (Collins 1995). The operational controls primarily address slowing sediment slurry production to the speed the suction pump can handle and/or keeping the cutterhead at or near the sediment surface.

Relevant Reports:

The following operational controls have been reported for cutterhead dredges (LaSalle et al. 1991, Collins 1995, Anchor Environmental 2003):

- Reduce cutterhead rotation speed – Reducing the rotation speed reduces the potential for side casting of sediment away from the cutterhead and slows production rate.

- Reduce swing speed of dredge head (ladder) – Reducing the swing speed ensures the dread head does not move through the cut faster than it can hydraulically pump the sediment. Typical swing speeds are 5 to 30 ft/minute (Anchor Environmental 2003).
- Increase pump rates – Increasing the suction rate will tend to reduce the amount of resuspended sediments around the cutterhead.
- Operate cutterhead below sediment surface – Maintaining, to the extent possible, the cutterhead just below the substrate surface minimizes sediment resuspension turbidity associated with partial cutting (some blade exposure) and fully buried cutting (sediment cave-in).
- Eliminate bank undercutting – Removal of sediment in lifts ≤ 80% of cutterhead diameter reduces cave-ins and sloughing.

Consideration of Effectiveness:

Collins (1995) provides a comprehensive review of the factors and effectiveness of most of the above-noted operational controls. That reference is the primary basis for the following summary of effectiveness considerations. The rotation speed of the cutterhead and swing speed of the dredge head are primary factors that influence the amount of sediment resuspension and may be optimized by dredge operators to control turbidity. The direction of the ladder swing relative to cutterhead blade rotation also is important, with greater resuspension when the cutterhead is overcutting (shear velocity higher) than undercutting (shear velocity lower). This generally is more pronounced with cohesive than non-cohesive sediments. Increasing the rate at which the slurry is drawn into the suction pipe may reduce the amount of sediment around the cutterhead.

Maintaining the cutterhead below the sediment surface has been shown to significantly reduce resuspension compared to partial burial (exposure of blades above the mudline allows more opportunity for wash off) and deep burial (results in slouging and cave-in along the dredge path). Maintaining the cutterhead below the sediment surface also reduces entrainment rate (Section 6.4.3.2).

Hopper Dredges

Sediment resuspension from a hopper dredge results when hoppers are intentionally overfilled so excess water runs overboard while greater density is achieved in retained sediment-laden slurry; this practice is used to maximize sediment load. Spillage also may occur while the vessel is underway if hoppers are too full. Operational controls address minimizing intentional overflows and/or unintentional spillage. In addition, a water recirculation system may be used to return overflow waters to the draghead.

Relevant Reports:

The following operational controls have been reported for hopper dredges:

- Eliminate Overflow – Minimizing sediment overflow spillage from the vessel reduces turbidity plumes and suspended sediment concentration (LaSalle et al. 1991, Collins 1995, Anchor Environmental 2003).
- Reduce Fill Level – Lowering the hopper fill level minimizes overflow spillage during rough sea conditions (Anchor Environmental 2003).
- Use a Recirculation System – Recirculation of overflow water to the draghead may increase sediment load in hopper (Anchor Environmental 2003).
- Equip with morning glory spillway – This conveys overflow water subtidally.

Consideration of Effectiveness:

Hopper dredge overflow produces substantially higher (e.g., an order of magnitude) suspended sediment concentrations than the dredging action itself (reviewed in LaSalle et al. 1991, Section 5.5.2.2). This results from the high suspended sediment concentration of slurry waters only having a short retention time in the hoppers (Collins 1995). Therefore, elimination of intentional overflows should be effective for reducing turbidity. A reported disadvantage of this operational control is increased costs and project duration due to less efficient production rates (Anchor Environmental 2003).

Use of a morning glory spillway that conveys overflow water 15 to 20 ft (4.5 to 6 m) below the water surface to reduce surface turbidity was listed as a conservation measure in the biological opinion for the 2001 2001 San Diego Regional Beach Sand Project (USFWS 2000), which was specified as requirement in the 404 permit for that project (USACE No. 1999-15076-RLK). Monitoring showed that depression of water clarity was primarily within 500 ft (152 m) of the dredge (Section 5.5.3.5, Figure 5.5-7) and turbidity plumes complied with permit requirements (i.e., ≤ 1 hectare, 2.47 acres) with few exceptions (AMEC 2002). Therefore, this measure appears to be effective at controlling surface water turbidity.

Other measures such as recirculating overflow water near the draghead and/or discharge of overflow water to mid-depth or deeper water enable more efficient production rates and reduce surface turbidity, which may be effective for meeting water quality Receiving Water Limitations. Those measures may increase suspended sediment concentrations at depth beyond that without overflow, which should be taken into consideration if sensitive habitats (e.g., reefs, SAV, spawning grounds) are in the vicinity.

Limiting the hopper fill level addresses unintentional overflows during rough seas, which may be more or less effective depending on existing conditions

Halt operations

Relevant Reports:

- Anchor Environmental (2003) reported that halting dredging can be an effective measure for reducing turbidity during periods of extreme tidal fluctuation when currents are strongest.
- RGP 67 specifies that if turbidity is greater than one-half mile from discharge site (either upcoast or downcoast) for five (5) consecutive days, the discharge shall be halted or modified to reduce turbidity.

Consideration of Effectiveness:

Halting construction operations may be necessary to stop significant and/or unpermitted adverse impacts, if necessary, until operations can be modified to reduce turbidity to acceptable levels or until environmental conditions moderate. This measure may be effective when implemented infrequently, but may increase project duration and costs if frequent halts to construction are required.

Inspection and Repair of Pipeline Leaks

This measure involves pipeline inspection and repairs to avoid and/or minimize sediment loss from hydraulic pipelines.

Relevant Reports:

- Leaky hydraulic pipeline connections may increase turbidity (LaSalle et al. 1991).
- Leaky hydraulic pipeline connections pose a threat to snowy plover nest sites, if present (Hutchinson et al. 1987).

Consideration of Effectiveness:

Sediment loss from pipeline leaks or breaks has the potential to increase suspended sediment concentrations and/or sediment burial in unwanted locations. This may be of particular concern in areas where pipelines are placed in close proximity to sensitive reef, SAV, and/or coastal strand habitats. Pipeline leaks deposit fine aprons of sand, making the area homogenous and unsuitable for snowy plover's, which require the sand surface to be heterogeneous to camouflage their nests (Hutchinson et al. 1987).

Periodic inspections of above water pipelines should be effective for early problem identification and repairs. This is of particular importance in areas where snowy plovers may be nesting. In areas lacking nesting activity, increased turbidity is the primary concern. Monitoring of the discharge should be effective for detection of a drop in production rate that may signal a pipe break. Turbidity monitoring may be effective for detection of a substantial change in surf zone or nearshore turbidity characteristics that may signal pipeline leakage.

6.4.4 Construction Methods and BMPs

Best management practices (BMPs) may be implemented during dredging and/or discharge activities to control turbidity and/or other discharges.

6.4.4.1 Use Silt Curtains or Gunderbooms to Minimize Turbidity

Turbidity sometimes is controlled by use of silt curtains, which are flexible, vertical barriers, constructed of permeable or impermeable materials. Francinques and Palermo (2005) reviewed that there are three types of devices that have been used to control turbidity, which sometimes are generically referred to as "silt curtains":

- Silt/turbidity curtain – Impermeable barrier to contain turbidity. Usually deployed from surface to within 1 to 2 ft (0.3 to 0.6 m) of the bottom.
- Silt/turbidity screen – A permeable barrier that allows water flow-through and retains suspended sediment.
- Gunderboom – A turbidity screen modified by addition of adsorbent geotextile material to control oil spills. Usually deployed from surface to bottom.

Francinques and Palermo (2005) reviewed that silt curtains are generally constructed of polyester-reinforced thermoplastic (vinyl) fabric that is maintained in a vertical position by floatation material at the top and a ballast chain along the bottom. The Depending on water depth and type of sediment management activity, silt curtains may or may not extend to the bottom substrate. Silt curtains are designed to control the dispersion of turbidity and facilitate suspended sediment settlement, but do not prevent turbidity outside the area of deployment. When there is hydraulic discharge, a gap between the bottom of the curtain and substrate is maintained to allow escape of fluid mud, which otherwise could accumulate and bury the curtain.

Silt curtains may be deployed in several different configurations (e.g., circular, elliptical, semicircular, U-shaped, maze of two or more curtains) (Francinques and Palermo 2005). Generally, deployment configurations are based on physical, hydrodynamic, and vessel traffic considerations.

Relevant Reports:

- Francinques and Palermo (2005) reviewed that silt curtains are most effective in areas with slow to moderate currents, stable water levels, and relatively shallow depths. The effectiveness of silt curtains is reduced under the following conditions:
    - Strong currents (> 1 to 1 ½ knot are problematic). In high currents, silt curtains may be difficult to maintain and can easily become dysfunctional.

- Fluctuating tide levels. Anchoring on both sides of the curtain is recommended prevent the curtain from overrunning the anchors and pulling them out when the tide reverses. Extra curtain length (10 to 20 %) and depth (slack) should be included to allow for tidal fluctuations and exchanges of water within the curtain.
- Water deeper than 10 to 15 ft (3 to 4.5 m). At greater depths, loads or pressures on curtains and mooring systems become excessive and could result in curtain failure.
- Excessive wave heights (including ship wakes).
- High winds. Can lift curtains like a sail.
- Drifting debris and/or ice.

- Anchor Envioronmental (2003) reviewed that silt curtains, if deployed properly, can protect adjacent resources and control surface turbidity, but have no effect on bottom turbidity (where turbidity is highest). They also reviewed that gunderboom advantages included surface to bottom turbidity control and water exchange, but greater expense and potential clogging by silt were considered disadvantages.
- Chambers Group (2001) reviewed that silt curtains can be effective under calm conditions, but they require substantial maintenance, can be difficult to hold together, may become fouled, and storms can dislodge anchors.

Consideration of Effectiveness:

Use of silt curtains appears to be effective at containing turbidity within localized project areas in embayments where current speed and water depth

6.4.4.2 <u>Use Dikes or Swales to Minimize Turbidity</u>

This measure involves construction of temporary sand dikes or swales where hydraulically pumped materials would be discharged to slow the rate of release to the swash zone. This measure is designed to settle sands on the beach and minimize turbidity in the nearshore.

<u>Longitudinal Dikes</u>

Temporary earthen berms (dikes) may be created parallel to shore during beach nourishment to reduce turbidity of return water from hydraulic pumping of sands to the beach.

Relevant Reports:

- This method and/or single-point surf zone discharge has been widely applied to projects to minimize potential impacts to snowy plovers and/or California grunion (USACE 1993, 1994a, 1998a, 1998b, 2000a, 2001), to minimize turbidity effects on least tern foraging (USACE), and/or to minimize turbidity (U.S. Navy 1997a, b).
- This method was used during the 2001 San Diego Regional Beach Sand Project, and apparently was effective since turbidity was largely restricted to the surf zone (AMEC 2002).

- This method also was used during the Surfside-Sunset beach nourishment project; least tern monitoring showed no apparent influence between turbidity plumes and least tern foraging behavior (MEC 1997).

Consideration of Potential Effectiveness:

Limited data indicate diked discharges may be effective in lessening turbidity plume effects outside the surf zone. Data also suggest that resulting turbidity plume characteristics do not result in obvious alteration of least tern foraging behavior; although, catch success rates within and outside plume areas have not been compared.

Swales

Temporary earthern swales may be created during beach nourishment to reduce turbidity associated with pumping sands to the beach.

Relevant Reports:

- This method was employed during the Goleta Beach Nourishment Demonstration Project, and apparently was effective based on turbidity being localized and restricted to the surf zone (Moffatt & Nichol 2003).

Consideration of Potential Effectiveness:

Monitoring information indicates that use of dikes and/or swales are effective in lessening turbidity plume effects outside the surf zone (AMEC 2002, Moffatt & Nichol 2003). Data also suggest that resulting turbidity plume characteristics do not result in obvious alteration of least tern foraging behavior (MEC 1997); although, catch success rates within and outside plume areas have not been compared.

6.4.4.3 Minimize Potential Hazardous Materials Leaks or Spills

Accidental leaks and/or spills are of concern because of potential impacts to water quality and/or biological resources.

Mitigation Measures:

- All equipment shall be inspected for leaks (especially hydraulic lines, fittings, and cylinders) and the equipment cleaned each day or shift that the equipment is to enter the water. Equipment will be cleaned and repaired (other than emergency repairs) at least 500 ft (152 m) from the high tide line. No equipment with leaks will be allowed on the beach or to operate in waters.
- All contaminated water, sludge, spill residue, or other hazardous compounds will be disposed of at a lawfully authorized designation.
- Use biodegradable, nontoxic, vegetable-based hydraulic oil rather than petroleum-based hydraulic oil when practicable.

Relevant Reports:

RGP 67 (USACE 2006) specifies that all equipment shall be inspected for leaks immediately prior to start of beach operations and regularly inspected thereafter until project completion, and vehicles with leaks shall not enter the beach area; and equipment shall be cleaned and repaired (other than emergency repairs) at least 500 ft (152 m) from the high tide line, and all contaminated water, sludge, spill residue, or other hazardous compounds will be disposed of at a lawfully authorized designation

Best Management Practices for Erosion & Sediment Control—Instream Works

City of Kelowna

July 21, 1998

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Table 1 Applicable Conditions for Instream Works

Method	Parameter	Conditions
Staked Silt Curtain	Flow velocity less than 0.25 m/s	• Water Depth less than 1.2 m • Generally, cross no more than 30% of stream width.
Floating Silt Curtain	Flow velocity less than 0.15 m/s	• Water Depth greater than 1.2 m • Generally, cross no more than 30% of stream width.
Cofferdams	Flow velocity greater than 0.25 m/s	• Limited only by financing • Can cross entire stream width if flow can be pumped around site.
Water Structures (e.g., *Auadam®*)	Flow velocity as per manufacturer's recommendations. Generally low flow or standing water.	• Water depth limited to size of water structure and to steady water levels. • Flat-bottomed streams free of sharp rock or large debris. • Can cross entire stream width if flow can be pumped around site.
Instream Weirs (small dams)	Low flows and/or broad areas	• For settlement of coarser suspended material only.

Best Management Practises for Erosion & Sediment Control--Instream Works

1 *Applicable Activities*

Construction activities in or beside a watercourse are unavoidable for many types of developments. The methods to control sediment in this manual can be applied to, but not limited to:

- Bridge construction including cribs, abutments, piers
- Instream or adjacent excavations
- Instream fill placement
- Stream bank revetment works (erosion protection)
- Control of sediment from adjacent construction
- Buried utility water crossings (e.g., pipelines, fibre-optic cables, buried power lines)
- Dredging of marinas
- Docks and boat launch construction
- Protection of a sensitive area from sediment and turbidity

2 *Background*

2.1 Legal Requirements

The Fisheries Act provides for protection of fish and their habitat. The proponent of a project that may alter fish habitat may be required to submit information about the proposed project for scrutiny by Fisheries management authorities.

The Section 9 Regulation of the Province's *Water Act* provides a set of standards under which an applicant may undertake certain types of changes in or about a stream. The standards ensure changes are carried out in an environmentally sensitive manner in order to protect water quality and quantity and the aquatic and riparian environment.

Any instream work may require an Approval from BC Environment.

An Approval under the Navigable Waters Protection Act may also be required depending upon the specifics of the particular project.

Many of the impacts that may occur to fish habitat could be reduced or eliminated by scheduling instream activities during appropriate times of the year. BC Environment can provide guidance in this regard. Call 1-800-461-1127.

2.2 Management of Sediment

During instream construction, soil particles introduced into suspension are difficult to intercept and remove from the water. This is especially true in a flowing environment condition, which continues to mix and transport. The best approach is to restrict the work area to as small an area as possible, and to isolate this area from the rest of the watercourse. This will accomplish the following:

- **Control at the source:** flow is minimised through the work area, dramatically reducing the quantity of soil lost into suspension.
- **Sediment interception:** most of the soil introduced into suspension is contained within the isolated area, where it can settle or otherwise be removed.

The main purpose of the isolation area is to eliminate the opportunity for flowing water to capture disturbed and exposed fine particles then transport them away to settle elsewhere. Isolating the work area will also achieve some settlement of suspended material within the area but this is a minor benefit, not the primary goal. The quantity of settled material in an enclosed work area typically represents only a fraction of what would be transported without isolation.

Design silt barriers to isolate the instream work area from as much of the watercourse as possible. **Do not use silt barriers to filter suspended particles from the water column.**

As the effects of sediment deposition become more widely understood, sediment transport control techniques come under closer scrutiny. It is now clear that silt barriers are not capable of filtering stream flow and installing silt barriers across flowing waterbodies often makes a bad situation worse.

3 *Instream Sediment and Turbidity Controls*

3.1 General

The generation of sediments cannot be avoided during instream construction. It can be controlled and reduced. Several instream methods have been developed to physically control sediment and turbidity resulting from construction operations. These methods include the use of silt barriers, cofferdams, instream weirs, and settling ponds or pools.

The use of instream sediment controls described in this manual should not be the only measures used to control sediment. Use these techniques with land based erosion controls and proper construction practices, to minimize the amount of sediment introduced into a watercourse.

4 Silt Barriers

Silt barriers are temporary flexible barriers used within a watercourse to separate or deflect natural flow around a work area. In general, there are two types of silt barrier:

1) Staked (Figure 1)
2) Floating (Figure 2)

Each type of barrier is suited for a different situation and has a unique set of requirements for good performance.

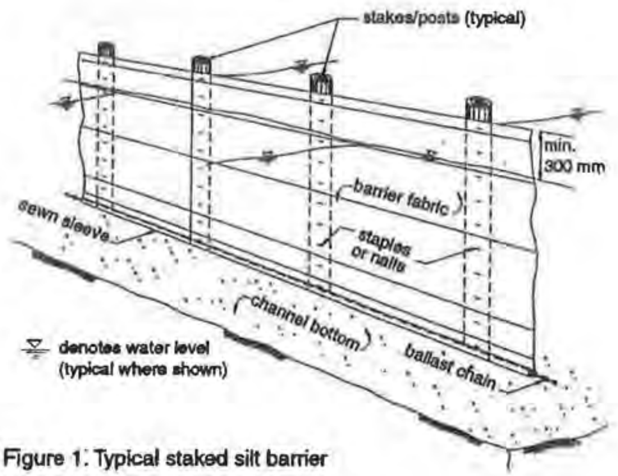


Figure 1. Typical staked silt barrier

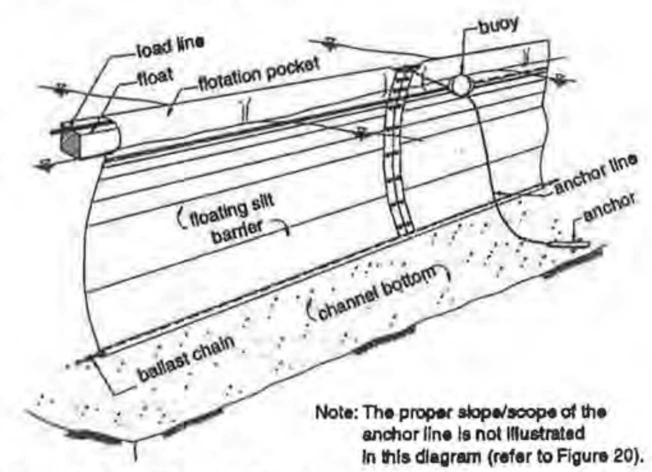


Figure 2. Typical floating silt barrier

4.1 Placement Configurations

Silt barriers (staked or floating) effectively isolate construction activities from the watercourse or lake. The most effective placement is either:

- A semicircle or U-shaped configuration anchored to shore (Figure 3).
- A circular or elliptical shape (Figure 3).

Manufacturers of silt barriers sometimes promote the placing of a barrier completely across stream flow as an effective way to control turbidity and sediment. This configuration is not recommended. It simply drives the turbid water under or around the barrier and is largely ineffective. This type of configuration may also result in additional sediment and turbidity. The constricted flow and resulting faster water velocities under or around the barrier cause scouring of the channel bed.

Silt barriers should NOT be installed completely across channel flows.

When isolating part of a flowing stream, try to limit the isolated portion to less than 1/3 of the stream width. However, under many circumstances related to stream flow, channel shape, and isolation technique, it may be possible to isolate as much as 2/3 of a stream width.

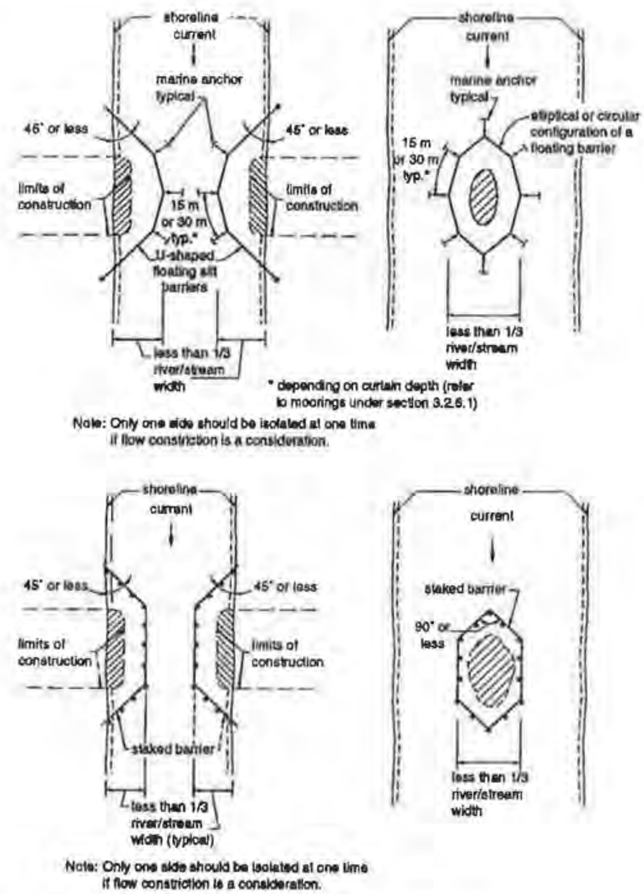


Figure 3. Effective silt barrier deployment configurations.

When isolating a portion of stream flow, remember that the current velocity in the remaining channel will increase. This will increase the potential for erosion. It may be necessary to install erosion protection on the opposite shoreline or downstream to limit this potential. Consult qualified engineering staff when considering design of such measures.

4.2 Applicable Conditions for Silt Barriers

Ask the following questions when deciding whether to install a silt barrier (staked or floating) at a site:

1. Are the flow conditions at the site favourable for a silt barrier (i.e., not subject to fast currents, waves, strong winds, ice flows)?
2. What are the characteristics of streambed that will be disturbed (e.g., clays & fine silts, or coarse sands and cobble)?
3. Can an enclosure be provided around the construction area?
4. What is the natural sediment load or bed load of the stream during a full range of conditions (e.g., spring freshet, strong winds, waves)?
5. What is the impact to surrounding environment if no containment is provided?
6. Are there suitable alternatives?

Silt barriers cannot be used effectively in all types of flow conditions.

Fast flowing currents and high turbulence can significantly reduce the effectiveness of a silt barrier. The currents floating silt barriers to flare, or result in minor to complete loss of the staked or floating barrier. Strong currents, waves, ice, floating debris and boats can damage or destroy silt barriers.

Table 2 - Applicable Conditions for Silt Barriers

Configuration	Parameter	Staked Barrier	Floating Barrier
Completely across intermittent flowing swales or ditches	With negligible flow	✓[1]	n.a.[2]
	With flow	✗[3]	✗
Completely across a water body	With negligible flow	✓	✓
	With flow	✗	✗
In "U" or elliptical shaped configurations[4]	Velocity[5] less than 0.15 m/s	✓	✓
	Velocity[5] between 0.15 m/s and 0.25 m/s	✓[6]	✗
	Velocity[5] greater than 0.25 m/s	✗	✗
Conditions		Staked Barrier	Floating Barrier
Water depth	Less than 800 mm	✓	✗
	Between 800 mm and 1.2 m	✓	✓
	Greater than 1.2 m	n.a.	✓
Water height	Less than 150 mm	✓	✓
	Greater than 150 mm	✗	✓
Impact by ice flows		✗	✗

1. ✓ - applicable
2. n.a. – not applicable
3. ✗ - not recommended
4. As illustrated in Figure 3
5. Current velocity where the barrier is to be placed
6. The use of additional silt barrier supports as described in the following sections.
7. For depths greater than 6 m, consult a qualified engineer on the design of the barrier.
8. For depths greater than 3 m, the wave height should not exceed five percent of the water depth.

4.3 Field Survey

To design an effective silt barrier, first collect critical information at the proposed location. Measure the site to get the following:

1. Current Velocity

Establish the speed and direction of the water where the barrier will be installed. Measure the current using a current meter, or drop a small piece of wood into the current and measure the distance it travels downstream over time. The velocity is the distance divided by the time (i.e., 10 m in 40 seconds = $10/40 = 0.25$ m/s). When using a current meter, the average velocity at the measurement point is at 0.6 of the channel depth at that point.

Current varies significantly across a wide channel (greater than 15 m) and at different depths. Take current velocity measurements at a minimum of three points: (see next page)

1. Midway between the shoreline and the proposed edge of the silt barrier.
2. At the anticipated edge of silt barrier.
3. At least one measurement in the rest of the channel to get a representative velocity.

Calculate the approximate increased velocity by dividing the existing water velocity by the part of the channel that will not be blocked by the barrier.

Example:

A channel has an existing velocity of 0.10 m/s. The proposed barrier will block 20% of the channel, leaving about 80% open. The velocity of flow in the unblocked channel would be 0.10/0.80=0.125 m/s. This is the approximate flow that the barrier would have to withstand.

2. Water Depth

If the currents appear to be suitable for silt barrier deployment, conduct a survey of the water depths at the proposed site. Measure water-depth using a weighted cord or long rod for shallower depths. Measure depths from the shoreline out to edge of the area where the barrier will be placed.

Remember that changes in water depth can occur and water levels could rise within a few hours of a significant rain. To anticipate the water level at the time of construction, look for clues such as the vegetation type or scour lines at shoreline.

3. Sediment Type

The type of bottom sediment indicates what type of geotextile and anchors to use. Sediment type will also affect the scheduling of the barrier removal.

Take soil samples from the channel bottom that are representative of the material that is expected to be disturbed during construction. Collect using a grab sampler or a coring tool and take them to a laboratory for analysis to determine particle size distribution. For a quick reference, estimate the soil type by visual observation and using Table 2.

4. Soil Particle Transport

Table 3 summarises the approximate distances downstream where settling of specific sized particles is expected. The calculations were based on a stream with a depth of 2.5 m and a water velocity of 0.3 m/s. It is important to note that turbulent water may transport soil particles significantly farther than the distances estimated in Table 3.

Settling velocities of varying sized soil particles will affect scheduling of silt barrier removal. The smaller the particle, the longer the period required to settle to the bottom of the barrier. Once particles have settled out, the barrier may be removed.

Table 3 - Visual/Manual Procedure for Identification of Soil Types

Soil Type	Description[1]	Identification Technique[2]
Sand	Small particles of rock with particle diameters between 2.0 mm and 0.06 mm	• sieving • individual particles are easily visible • feels grainy when soil is rubbed between fingers
Silt	Soil particles with diameters between 0.06 mm and 0.002 mm	• sieving and hydrometer analysis • gritty texture when particles are rubbed between fingers or tasted, but individual grains cannot be identified • crumbles when attempting to roll a moist sample into a thread approx. 3mm in diameter • powders when soil is allowed to dry • dull appearance when a firm moist sample is cut with a blade • moisture film comes to the surface when a moistened sample is squeezed, then shaken in an open hand
Clay	Soil particles with diameters less than 0.002 mm	• sieving and hydrometer analysis • smooth texture when particles are rubbed between fingers or tased • a moist sample can be rolled into a thread approx. 3mm in diameter • hard to break when soil is allowed to dry • shiny appearance when a firm moist sample is cut with a blade • no moisture film comes to the surface when a moistened sample is squeezed, then shaken in an open hand

1. Following the 'modified' Massachusetts Institute of Technology soil classification system. For comparison, the forestry classification manual has the following sizes for the primary particles: sand (2mm to 0.05mm); silt (0.05mm to 0.002mm); and clay (<0.002mm).
2. Soil samples may contain a combination of the different soils types, and as a result, have characteristics of two or more soil types.

Table 4 – Sediment Transport Distances

Particle Size	Spherical Diameter	Settling Velocity	Distance Downstream where Deposition is Expected
Coarse Sand	2.0 mm	0.23 m/s	4 m
Medium Sand	0.6 mm	0.07 m/s	14 m
Fine Sand	0.2 mm	0.019 m/s	49 m
Coarse Silt	0.06 mm	0.0019 m/s	495 m
Fine Silt	0.006 mm	0.000025 m/s	36,600 m (36.6 km)

Notes:
1. Uniform flow assumed, with some estimate for the effects of turbulence; based on work done by Hazen.
2. Water temperature assumed to be 10 C.
3. Turbulent flow will increase transport distance.

5. Other

Observations that should be made during the field survey include:

- Convenient anchoring points for the silt barrier. These could be existing pilings, bridge supports, large trees, etc.
- A location for launching and retrieving the silt barrier.
- Boat traffic in the area. This will affect wave conditions and navigational markings that are used on the barrier and mooring system.

4.4 Staked Silt Barriers

A staked silt barrier consists of a fabric (e.g., geotextile, reinforced fabric) attached to stakes or posts and a chain sewn into a sleeve along the bottom edge to allow the barrier to conform to the channel. In many cases, a wire support fence is also used to provide additional strength behind the geotextile (Figure 4).

Staked silt barriers can be used to isolate the work area from stream flow. For installations that isolate part of the stream (Figure 3), barriers can be sued in flow conditions that do not exceed 0.15 m/s. If additional anchoring is provided, flows up to approximately 0.25 m/s can be accommodated.

4.4.1 Materials

The materials and specifications in this section have been proven effective in the field, or are industry standards. Alternative materials are presented, so that readily available materials at a work site can be used without having to buy expensive commercially available products.

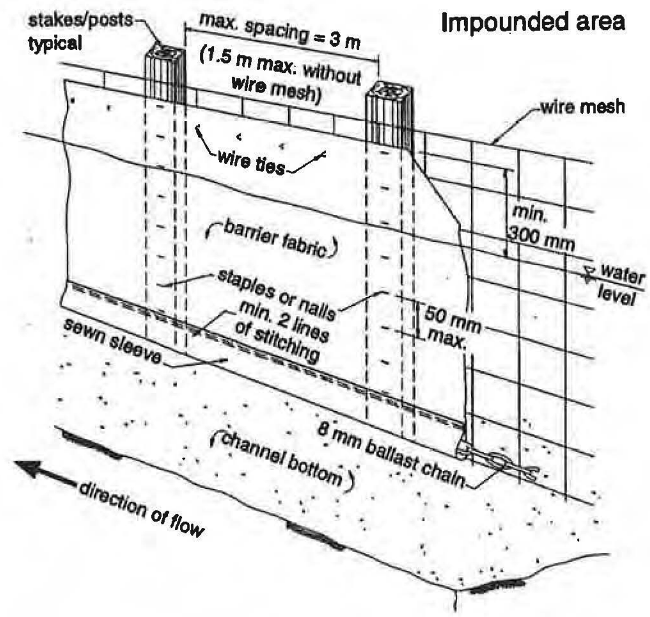


Figure 4 – Typical Construction of a Staked Silt Barrier

Geotextile Fabrics—used for barriers may be either permeable or impermeable. **Impermeable fabrics** may be suited for situations where there are no sources of water within the barrier. **Permeable fabrics** will allow some water to pass through small openings; however, over time the fabric will become plugged up with fine material and begin to act as an impermeable barrier. Permeable barriers are better suited where construction results in the removal or addition of water within the enclosed construction area, such as, through excavation or pumping. Permeable fabrics will allow the water levels to equalise more readily than an impermeable fabric will.

Woven fabrics are recommended over non-woven type fabrics for two reasons:

1. Non-woven type fabrics stretch considerably more than woven geotextiles when placed in tension.
2. Non-woven fabric can trap sediment, causing the fabric to sink or sag.

Woven type geotextiles have distinct crossing pattern. Non-woven type fabrics have a random fibre construction.

See Table 4 for some recommendations on specifications of the various materials used in staked silt barrier applications.

Alternative materials may not be applicable in all situations.

Table 5 – Staked Silt Barrier Requirements

Material	Parameter	Recommended Value
Geotextile Fabric (permeable)	Material	Woven[1]
	Grab tensile strength (ASTM D4632 or equivalent	900 N[2] (202 lb.)
	Ma. Apparent opening size (ASTM D4751 or equivalent)	0.21 mm (0.0083")
	Useful temperature range	+35 C to –30 C
	UV[3] Resistance	Required
Geotextile Fabric (impermeable)	Grab tensile strength (ASTM D4632 or equivalent	900 N[2] (202 lb.)
	Useful temperature range	+35 C to –30 C
	UV[3] Resistance	Required
Wooden Posts	Min. diameter	65 mm (2.5")
Wooden Stakes[4]	Min. size	50mm x 50mm (2"x2")
Steel Posts (standard "U" or "T" section)[4]	Min. weight	2 kg/m (1.3 lb./ft)
Wire Fence Reinforcement (if used)	Gauge	14
	Type	Galvanised
	Max. mesh spacing	150mm (6")
Chain (if used)	Type	Non-corrosive
	Size	8mm (5/16")
Clean Rock fill (if used)	Min. diameter	50mm (2")

Notes:
1. Woven fabrics are distinguishable by a distinct crossing pattern in their appearance.
2. N–Newton
3. Ultraviolet
4. Item can be used in replacement of wooden posts.

4.4.2 Staked Barrier Installation

Follow these guidelines when using a staked barrier to confine a portion of the watercourse:

1. Place barrier at least 300mm above the waterline to prevent over-topping by waves or fluctuations in water level. For Safety reasons, do not install in a watercourse exceeding 1.2m in depth since it is staked manually by having crewmembers wade out into the water.
2. If wire fence reinforcement **is not** used, place the support stakes a maximum 1.5m apart. Drive stakes a minimum of 600mm into the channel bottom. Place supports closer in higher flow situations to ensure stability.
3. If wire fence reinforcement **is** used, place posts 3.0m apart. Fasten the wire mesh securely against the geotextile or fabric with heavy-duty wire staples (at least 25mm long) or with tie wires.
4. Where possible, use a continuous roll of geotextile or fabric, cut to the length of the barrier. This will improve the strength and efficiency of the barrier. If this is not possible, construct proper joints (Figure 5).
5. Fasten the fabric securely to the support posts with heavy-duty staples or nails (with a washer) at a maximum spacing of 50mm. Use tie wires to securely attach the fabric to the wire mesh (if used).
6. Where possible, prefabricate a staked barrier on shore. Then carefully roll it up lengthways to avoid tearing, and move it to the placement site.
7. Secure the bottom edge of the fabric to the channel bottom by placing a heavy chain into a sewn sleeve along the bottom edge of the barrier, or carefully lace clean rock fill (min. 50mm in diameter) over the bottom edge of the fabric. When using rock fill to secure the fabric to the channel bottom, place it on the outside of the enclosed area.

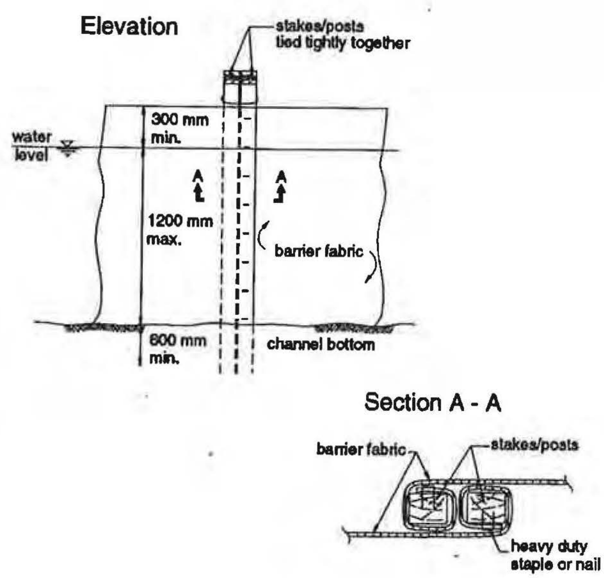


Figure 5 – Recommended method of joining sections of the staked barrier

Maintenance

- Inspect the silt barrier daily or after any significant rain event. Make required repairs immediately.
- Inspect the barrier for turbidity leaks that might be caused by holes in the submerged barrier.
- Replace torn fabric or geotextile with a continuous piece of fabric from post to post. Securely attach the fabric with staples or nails and weigh the bottom edge down with rock fill or with a chain sewn into a sleeve.

4.4.3 Additional Silt Barrier Support

Use of staked barriers is not recommended in flows of more than 0.25 m/s. If it is necessary to isolate construction areas in faster flows, a cofferdam may be required.

Prevent fast water from forcing over the staked barrier by using either of the following method(s):

1. Install a cable into a sleeve sewn along the top of the fabric to hold the upstream side of the barrier (Figure 6). Attach the ends of the cable or trees on the shore.

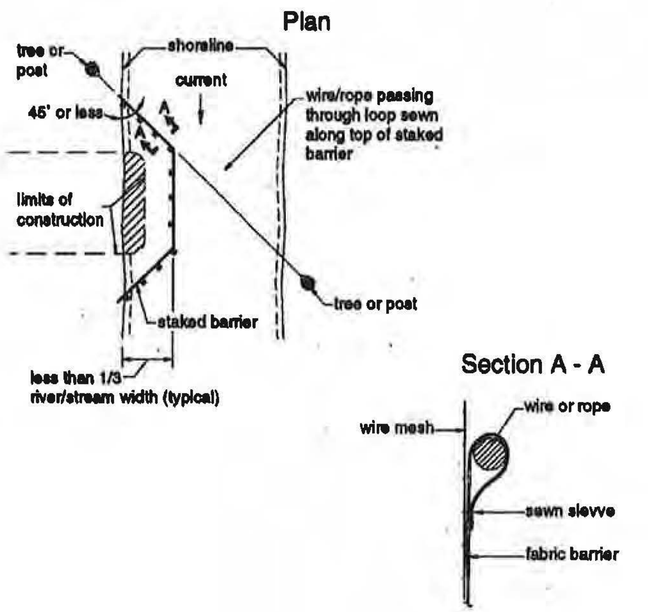


Figure 6 – Additional support provided to staked barrier using a cable or rope.

2. Place a log or steel beam from shoreline to shoreline across a small stream. Attach the top of the support posts and barrier to the log or beam to provide additional support. Attach the barrier fabric to the log by wrapping around the wood, strapping and nailing it to the upstream side. Do not let the log or beam block the stream flow.
3. Attach anchors or weights to the tip of the support posts as required. The anchors or weights will probably only be required along the upstream side of the barrier.
4. Place a rock fill cofferdam just upstream and around the side of the barrier (Figure 7). Place the partial cofferdam immediately upstream of the barrier and along the side of the barrier for at least 1/3 of the remaining barrier length; longer if eddies at the end of the cofferdam cause excessive forces on the barrier.
5. Where the current tends to undermine the barrier installation, place additional rock fill support on the bottom flap and/or behind the barrier.

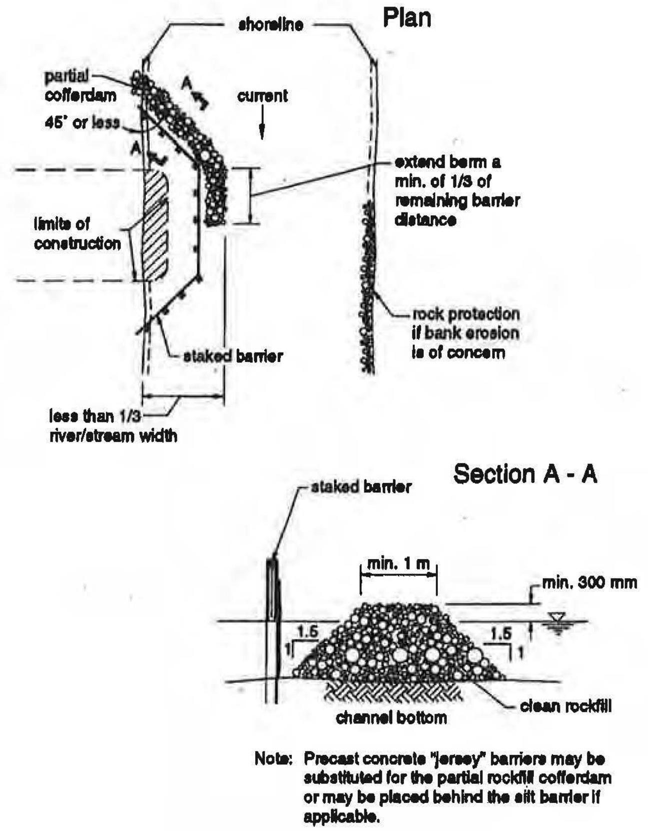


Figure 7 – Partial cofferdam used upstream of barrier to divert current

4.4.4 Removal

If the staked barrier is located within a watercourse, allow time for the suspended sediment to settle out before removal. The time required will depend on the depth of the water and the characteristics of the sediment in suspension. Refer to Section 4.6 for settling times of various particle sizes.

If it is not feasible to wait for the particles to settle, pump the turbid water and loose sediment behind the barrier onto a stable spill pad of rock fill or weighted timbers or plywood. Make certain the discharge area is a suitable open space that is well vegetated and will not drain into the watercourse (at least 50m from watercourse).

Reducing channel cross-section may require erosion protection downstream.

For a barrier located in a watercourse, follow these guidelines after the waiting period has elapsed.

- If the quantity is considered excessive, or if the deposited sediment is expected to move and cause problems downstream, excavate deposited sediment from the bottom of the enclosed area before the barrier is removed. Before excavating, make sure the procedure will not create more of a sediment problem by re-suspending particles.
- Begin removal of the barrier at one end and roll the barrier as it is gathered up.

4.5 Floating Silt Barriers

Floating silt barriers, also known as silt curtains, generally include four elements (Figure 8).

1. A skirt (e.g., geotextile, reinforced fabric) that forms the barrier
2. Floatation segments along the top
3. Weighting devices at the lower edge of the barrier
4. A load line built into the barrier above or below the floatation segments.

In low flow conditions, the skirt alone will absorb the force of the current. The load line is not required.

Use this type of barrier only in negligible or low flow conditions. Generally, a floating silt barrier can be used in a U-shaped configuration anchored to shore or in a circular or elliptical shape for flow velocities up to 0.15 m/s. Refer to Table 1 for applicable flow conditions and Figure 3 for placement configurations.

The floating silt barrier is probably the most misused form of sediment control.

The floating silt barrier is probably the most misused form of sediment control. A floating silt barrier is often thought to work the same way an on-land silt fence works. It does not. A floating silt barrier cannot stop, divert, or filter a significant volume of water.

4.5.1 Floating Silt Barrier Design

Materials

The materials and specifications presented for the design of floating silt barriers have proven effective in the field or are industry standards. Appendix B provides a list of sources and suppliers of many of the materials and products presented in this manual.

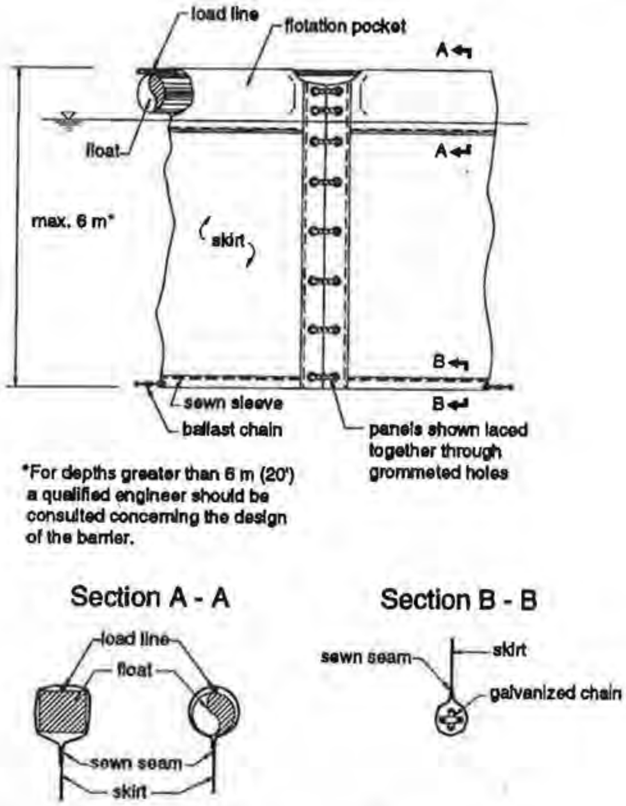


Figure 8 – Floating silt barrier detail

Barrier Fabric

The barrier fabric is generally a woven geotextile, canvas or tarp material, or a commercially available floating silt barrier or curtain. Common barrier fabric materials include nylon-reinforced polyvinyl chloride and polyester reinforced vinyl.

Non-woven geotextiles are not recommended for silt barrier applications for the following reasons:

1. Non-woven geotextiles stretch considerably
2. They plug-up with silt and tend to sink
3. Sediment trapped in the material can become re-suspended when the silt barrier is removed.

Non-woven geotextiles also absorb and retain water, which makes them heavy and difficult to handle.

Table 5 lists some barrier fabric specifications. Appendix A lists several permeable and impermeable fabrics and barriers that meet these specifications.

Table 6 – Silt Barrier Fabric Specifications

Parameter	Still Water[1]	Moderate Current[2]
Type	Woven geotextile, canvas/tarp material, or a commercial available silt curtain such as nylon reinforced polyvinyl chloride or equivalent	
Grab tensile strength (ASTM D4632 or equivalent)	900 N (202 lb.)	900 N (202 lb.)
Maximum apparent opening size (ASTM D4751 or equivalent)	0.21 mm (0.0082")	0.21 mm (0.0082")
UV[3] Resistance	Required	Required
Panel Lengths[4]	• 30m for depths less than 4m • 15m for depths greater than 4m	• 30m for depths less than 4m • 15m for depths greater than 4m

Notes:
1. An area that is calm and protected with no current, such as small lakes, ponds, and protected shoreline areas.
2. Current less than 0.15 m/s
3. Ultraviolet
4. For ease of handling and transportation. Individual panels/sections are typically shop fabricated and joined in the field.

Floatation

Maintain the silt barrier in a vertical position using floatation segments sealed into a sewn or heat welded seam along the top of the barrier. Alternate fastening arrangements using rope threaded through grommeted holes along the tip of the barrier to form the seam. Use continuous floats along the top of the barrier to ensure there is no gaps where the barrier is under the water.

A variety of materials may be chosen for use as floatation material including:

- expanded polystyrene
- ethafoam floats
- closed cell solid plastic foam floats

Table 6 recommends some of the properties of the floatation devices.

Timber log booms are not recommended as floatation devices. The recommended buoyancy factor of three cannot be achieved with a log boom because the specific gravity for soft wood timber is 0.75.

Ballast Chain

Weight the base of the skirt to prevent the barrier from billowing up and keep it in contact with the channel bottom. Sew or heat-seal a galvanised chain into a sleeve along the bottom edge of the barrier. It will easily conform to the bottom contours of the watercourse.

Table 7 – Floatation Specifications

Parameter	Still Water[1]	Moderate Current[2]
Type	Expanded polystyrene, ethafoam, or closed cell solid plastic foam floats	
Buoyancy Ratio[3]	> 3	> 5
Maximum Length[4]	3 m	3 m
Minimum Freeboard[5]	50 mm	100 mm

Notes:
1. An area that is calm and protected with no current, such as small lakes, ponds, and protected shoreline areas.
2. Current less than 0.15 m/s
3. Ration of Buoyancy (weight of displaced fluid) to barrier weight
4. To allow for ease of transportation, handling, and storage
5. To prevent overtopping under wind and wave conditions, and to support any downwind pull to anchors.

An alternative to using a chain is to attach weights, such as, concrete blocks to the bottom edge of the skirt. Space the blocks a maximum of 1.5m apart, and attach them to the fabric through grommeted holes with rope or non-corrosive wire. The individual weights must be equal to or slightly greater than the equivalent total weight per-unit-length as specified for the chain ballast (Table 7).

Timber log booms are not recommended as floatation devices.

Table 8 – Ballast Chain Specifications

Parameter	Still Water[1]	Moderate Current[2]
Type	Galvanised Steel Chain	
Size	10 mm (3/8")	13 mm (1/2")
Weight per length	1.9 kg/m	3.3 kg/m

Notes:
1. An area that is calm and protected with no current, such as small lakes, ponds, and protected shoreline areas.
2. Current less than 0.15 m/s
3. For depths greater than 4m (13-ft) use 13 mm (1/2") ballast chain.

Mooring

Anchor all silt barriers properly. Inadequate mooring systems will contribute to barrier ineffectiveness and failure. Use piles or posts tied back to a buried anchor or deadman, large diameter trees, or other immovable objects. Secure the rest of the barrier to marine anchors or piles (Figure 9).

The recommended mooring system consists of an anchor, chain, anchor rope, and mooring anc crown buoys (Figure 10). Anchor the barrier at the panel sections every 30m in a radial pattern (Figure 3). For barrier deeper than 4m, anchor the barrier every 15m. In some higher flow situations, reduce the anchor spacing.

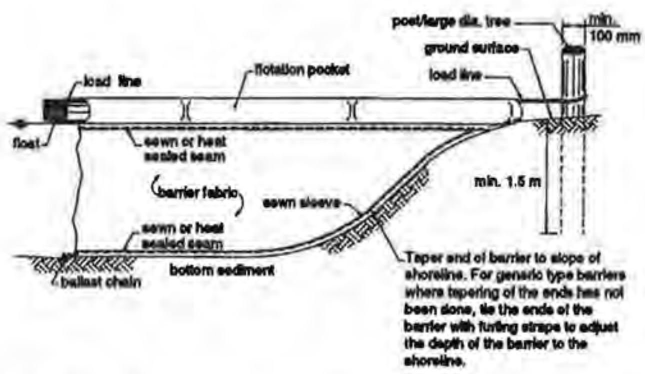


Figure 9 – Mooring of floating barrier to a post driven into the stream bank

To reduce pressure on the curtain, slant the barrier at a deflective angle, not perpendicular to the direction of the current or wave action (Figure 3). If the barrier will be exposed by reversing currents (as on large lakes), anchor it on both sides. The force on the anchor and line depends on the current velocity, anchor spacing, and the gap ratio (spacing between anchor and barrier length).

The holding power of an anchor is mainly determined by the angle from which the pull is applied. When the pull is almost parallel to the ground, the holding power is maximised. When the pull is from above, the holding power is negligible. The recommended scope (slope) for the anchor lines is 7 horizontal to 1 vertical (or length of line equal to seven times the water depth). Typically, a 13mm diameter nylon rope will provide sufficient strength for the anchor line.

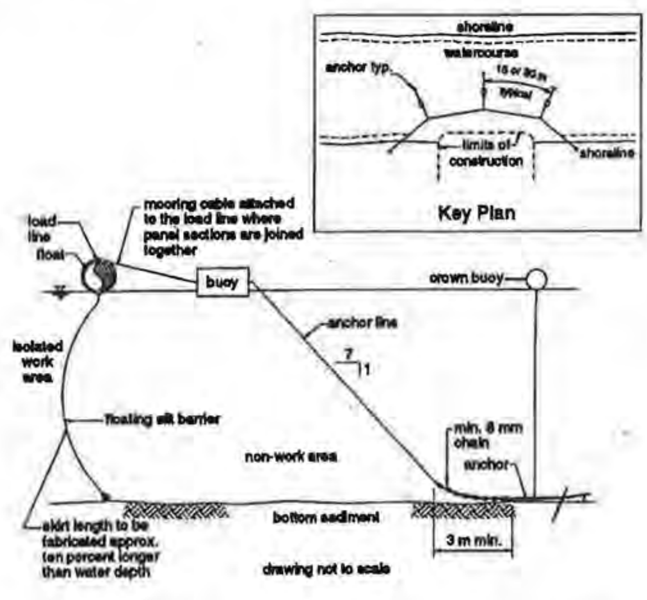


Figure 10 - Typical floating silt barrier anchorage system using marine anchors

Table 9 – Typical Maximum Holding Power of Various Anchors (N[1])

Size (kg)	Mushroom	Stockless	Concrete Block	Lightweight (Danforth) Type	
				Mud	Sand
4.5	80	130	20	2200	15500
11	220	330	50	5300	35500
23	440	660	110	6600	44400
34	660	1000	150	10200	66700
45	880	1330	220	12000	84500

Notes: 1. N – Newton
2. Adapted from: Johanson, E.E., 1978. *An Analysis of the Functional Capabilities and Performance of Silt Curtains. Technical Report D-78-39.* Dredged Material Research Program. US Army Engineer Waterways Experiment Station. Vicksburg, Miss.

The chain attached to the anchor and end of the anchor line has three purposes:

1. To prevent fouling (damage) of the anchor line or rope
2. To lower the angle of pull at the anchor (almost parallel to the channel bottom
3. To act as a shock absorber.

The chain acts as a shock absorber by helping to dissipate any sudden increased pull in the line.

Do not attach the barrier directly to pilings or posts driven into the bottom.

The anchor should be accompanied with a buoy (generally 300mm in diameter is sufficient) to warn day-time boat traffic. Mark the enclosure with warning light or navigational markers if there is night-time boat traffic.

An alternative method is to drive a post into the streambed. Do not, under any circumstances, attach the barrier directly to pilings or poles driven into the bottom. That may cause chafing of the barrier against the supports. For proper attachment, use load lines.

Load Lines

With negligible current velocities, no load line other than the fabric itself is necessary, but a line is required for anchor attachment. Place a rope in the sleeve with the floatation segments and attach the anchors to it. Directly attaching an anchor to the barrier fabric may cause excessive stresses on the fabric.

For moderate currents, a load line is required to absorb the pressure exerted by the currents. Connect the rope in the floatation sleeve to a post or other secure object. Make the load line slightly shorter than the barrier. Connect it so that the fabric is free to slide along the load line. Table 9 provides some specifications for load lines.

Table 10 – Load line Specifications

Parameter	Still Water[1]	Moderate Current[2]
Type	Nylon Rope	
Diameter	10 mm (3/8")	13 mm (1/2")

Note: 1. An area that is calm and protected with no current, such as small lakes, ponds, and protected shoreline areas.
2. Current less than 0.15 m/s

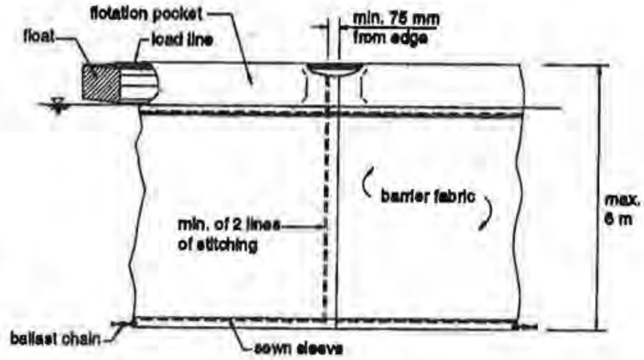


Figure 11 - Floating barrier panels joined together by a sewn seam

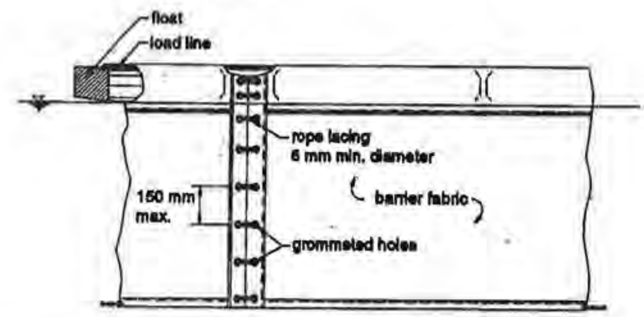


Figure 12 - Connected panels joined using rope lacing and grommeted holes

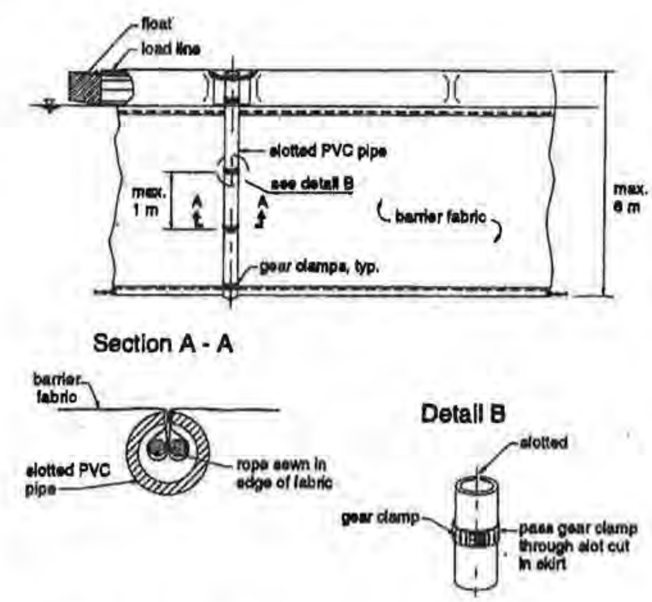


Figure 13 - Slotted PVC pipe connection

Panel Connectors

End panel connectors are designed to permit two barrier sections or panel to be attached, and to provide a positive water seal to limit leakage. There are four types or methods of connecting the ends of barrier sections.

1. Sewing the panels of fabric together (Figure 11). The thread (typically nylon or polyester) is generally available from the geotextile supplier. Use at least two stitch lines per seam, and a stitch density of two to four stitches per centimetre (six to ten stitches per inch). A locking chain stitch is recommended.
2. Join the panels of fabric using grommeted holes and rope lacing, if a portable sewing machine is not available (Figure 12). Make the holes slightly larger than the rope to minimize leakage.
3. Use a slotted PVC pipe with evenly spaced gear clamps to connect the silt barrier lengths. Sew 13mm diameter rope into the ends of each panel. When joining the sections together, slide the ends of the barrier down the slot in the PVC pipe (Figure 13).
4. Use aluminium slide-connectors, which are sometimes supplied with commercially available silt curtains (Figure 13). This is generally, an expensive option.

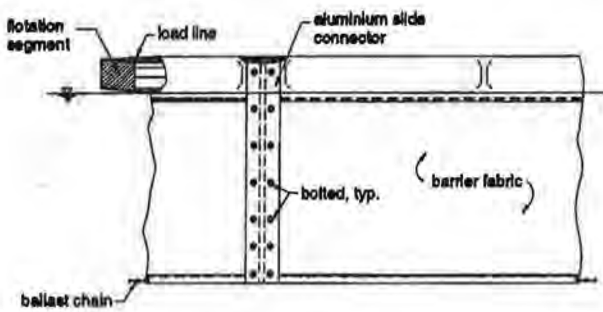


Figure 14 - Aluminum slide connector

4.5.2 Fabrication

There are a number of commercially available silt curtains. These barriers are typically constructed with nylon reinforced polyvinyl chloride fabrics, heat weld seams, and wire tension cables (load lines). Appendix B lists manufacturers and suppliers of these products.

Fabrication of silt barrier panels (i.e., seams, sleeves) can be done either by the geotextile manufacturer or distributor, or in the field. If the supplier does not have equipment to fabricate the barrier, try a tarpaulin, sail, or canvas product fabricator.

Fabricate custom panels in a sop. Join the individual panels in the field. The seaming of geotextile should follow the supplier's specifications. Generally, all seaming and stitching should be done a minimum of 75mm from the edge of the fabric with at least two stitch lines and a stitch density of two to four stitches per centimetre.

4.5.3 Design Considerations

Depth

Ensure the barrier will be in contact with the channel bottom at all points along the boundary of the enclosure. If the barrier is too short, turbidity and sediment may escape underneath the barrier. Make the barrier 10 % longer than the water depth to ensure it rests on the bottom.

Do not make the barrier too long since large pleats may develop along the bottom. Settling sediment will cover the pleats and may pull the barrier under.

Taper the ends of the barrier to the shape of the shoreline, otherwise sediment may build up in the pleats. Generic barriers that are not tapered can be adjusted by tying with furling straps to the shape of the shoreline (Figure 14). Inspect and maintain the barrier to avoid a build-up of sediment in the pleats.

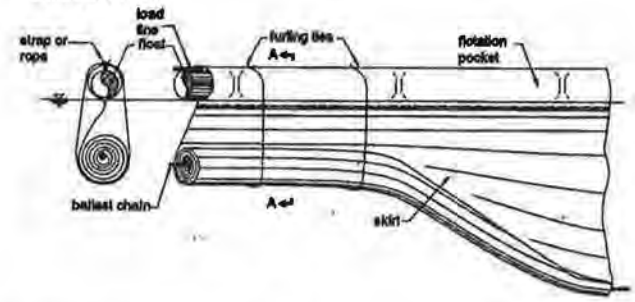


Figure 15 – Furling of skirt for deployment and/or recovery of barrier

The barrier may also "balloon" into the air near the shore. This occurs when excess pleats are pushed out of the water because the barrier is too long in the shallows close to the shore.

Area Enclosed

Make the area enclosed by the barrier as small as possible. Make sure the barrier is situated far enough from the construction to avoid damage from equipment, sloughing excavations and spoil piles, etc. Ensure that the bottom edge of the barrier is not buried by sediment or fill from the operations. If this occurs, the weight of the material accumulated along the bottom of the skirt can pull the barrier down.

Make sure the area enclosed by the barrier is as small as possible.

Length

Make the length of the barrier material 10 to 20 % longer than the straight-line length of the barrier enclosure. This will:

1. Compensate for measuring errors
2. Reduce the stresses on the barrier
3. Make installation easier.

4.5.4 Deployment

Exercise care when handling and transporting a silt barrier. Furl and tie it with lightweight straps or rope every 1 to 1.5 m. To furl the barrier, lay a section flat on the ground and roll it up lengthways starting from the bottom (Figure 15). Fold the furled and tied segments against each other accordion style, and tie them with heavy straps or rope. Carefully lift these packages into the transport vehicle. Do not drag them on the ground.

Launch a barrier from a ramp, pier, or shore. Unload it into the water by backing the truck down so that the tailgate is as close to the water as possible and then pull it out. Do not cut the furling ties at this stage or it will be very difficult to manoeuvre the barrier into place. Make sure the barrier will not scrape the bottom of the channel or truck tailgate as it is removed and join sections of the barrier as it is played out.

Set the shore anchor points and tie-off one end of the barrier to the upstream anchor point. Attach the downstream end of the barrier to a boat. Let the current and boat take the barrier to the downstream anchor point. Fasten the free end of the barrier to the downstream anchor point, and anchor the barrier in the designed configuration.

In setting marine anchors, lower the anchor gently to the bottom of the channel at a location that will give the recommended 7 horizontal to 1 vertical slope of anchor line. Put the boat in reverse, play out the anchor line fast enough so there is no load on the line, and set the anchor by applying tension to the line. Then attach the line to a mooring buoy attached to the load line of the floating barrier.

When the barrier is untwisted and deployed in the desired configuration, loosen the furling ties and let the ballast sink the barrier to the maximum depth.

4.5.5 Maintenance

Inspect the barrier each day for failures. Make the inspection from a small boat. Run the boat along one side of the barrier then the other. Inspect the following:

- Floatation device for abrasion, cuts, and holes in any seals
- Connectors for mechanical damage and tears in the fabric where they are attached to the skirt
- The submerged skirt for holes that may cause turbidity leaks
- The anchor assembly for broken lines or signs that the anchors have been dragged
- The barrier for indications that the bottom of edge is being buried by sediment (the barrier is gradually being pulled downward by the weight of the sediment). If this is occurring, remove the sediment that accumulates in the folds or pleats. Use a long handled brush, or raise the barrier a little to remove the silt in the pleats.

Repair moderate tears in the skirt following the specifications of the fabric manufacturer or distributor. Replace extensively damaged sections. Divers may be required to perform repair operations.

4.5.6 Removal Guidelines

Remove curtains after completion of the operation and after sufficient time has allowed for suspended sediment to settle out (refer to Section 4.6). Conduct the retrieval operation during periods of calm weather and low currents. Remove silt barriers carefully. Avoid using equipment, other than boats and hand-held equipment, within any watercourse. This prevents the stirring up and release of sediment and debris.

Re-furl the barrier during removal. Two people using a boat can accomplish this. Pull the barrier up, and furl and tie it with furling ties (approximately every 1 to 1.5 m) as the boat is moved along. When the entire skirt is furled, release the anchors and tow the barrier to shore.

If sediment accumulation on the bottom of the barrier makes removal difficult, the barrier may have to be removed by a diver cutting along the bottom of the barrier. Leaving the bottom portion of the barrier will cause less disturbance than pulling it all out. Unfortunately, with this method only part of the barrier will be salvaged.

Do not drag the barrier from the water with a vehicle unless the barrier is to be discarded. If necessary, remove the barrier in small sections by hand.

When flow is restored over the area protected by the barrier, or during spring runoff or storm events, some of the sediment deposited within the area may be eroded and transported downstream. See Section 4.6 for recommended strategies.

4.6 Timing of Barrier Removal

After instream construction is complete, wait for sediment to settle out before removing the silt barrier. The settling time will depend on the type of sediment and depth of water within the enclosure.

Some of the approximate settling times for various particle sizes are illustrated in Table 10. Colloidal particles, such as clay, will stay in suspension for a very long time. It may not be feasible to wait for the particles of this size to settle out entirely.

> After instream construction is complete, wait for sediment to settle out before removing the silt barrier.

Table 11 – Settling Time for Various Size Particles

Particle Size[1]	Depth (m)	Settling Time (hr)[2]
Coarse Silt (0.06 mm particle diameter)	2	0.3
	4	0.7
	6	1.0
	8	1.5
Medium Silt (0.02 mm particle diameter)	2	2.5
	4	5.0
	6	7.0
	8	10
Fine Silt (0.006 mm particle diameter)	2	25
	4	55
	6	80
	8	105
Clay (0.002 mm particle diameter)	1	5 days
	2	10 days

Notes: 1. Following the 'modified' Massachusetts Institute of Technology soil classification system. For comparison, the forestry classification manual has the following sizes for the primary particles: very fine sand (0.10mm to 0.05mm); silt (0.05 to 0.002mm); and clay (<0.002mm).
2. Based on a water temperature of 5 C and assuming still water (no turbulence).

Sediment Removal

Sediment that has been contained within the enclosure and has settled out—or sediment-laden water with colloidal particles that won't settle out quickly—may be removed before removing the barrier. Consideration must be given to whether this procedure will create more of a problem by re-suspending and dispersing sediment. Refer to Section 4.4.4 for methods and considerations when removing barriers.

Before removing the barrier, removal of accumulated sediment may be necessary.

One method to collect suspended sediment (enclosed within the barrier) is to pump out the turbid water and loose sediment and allow water to seep in from the other side of the barrier. Discharge the water onto a stable spill pad or fork fill or weighted timber or plywood. Make sure this discharge point is a well-vegetated area at least 50m from the edge of the watercourse.

Regulate the pumping rate to avoid a significant difference in water elevation on each side of the enclosure. Use a permeable geotextile as the barrier fabric.

Use a filter bag (commercially available) as an alternative to collect fines when dewatering. The bags are constructed of geotextile fabrics and are permeable enough to allow water to flow through the fabric while retaining most of the soil particles. To install, insert and clamp the discharge hose through a corner of the bag. Set the bag on flat well-vegetated area about 50m from the stream.

Another alternative is to fold the barrier down against the streambed or bank, toward the isolated area. This will encase accumulated sediment. Then cover the barrier with rock fill to permanently seal the sediment. This option must be reviewed by BC Environment staff with regard to the effects of altering the channel bottom and/or possibly reducing the carrying capacity of the stream.

5 Cofferdams

A cofferdam is a temporary structure used to enclose a work area or contain sediment and turbidity that may be introduced into the watercourse. Cofferdams can be constructed from various materials. Some of the common materials include:

- Rock fill (wire gabion optional)
- Concrete blocks (lock-block)
- Sandbags
- Polyethylene tubes (Aqua-Dam®)
- Wood sheeting
- Rock filled timber cribs
- Sheet piling

If dewatering is performed, the cofferdams must be provided with an impermeable synthetic liner or clay plug. If the underlying native soils have a high permeability, dewatering may not be possible unless sheet piling is provided. The pump discharge point should be in a well-vegetated area at least 50m from the edge of the watercourse.

If rock fill is used for the cofferdam, the material should be clean and of a low acid generating potential.

For some situations, a cofferdam may be constructed completely across the channel, upstream and downstream of the work site. Stream flow may be maintained by pumping around the work site with pipe, a channel diversion, or with flumes.

All proposed cofferdam installations should be designed and approved by engineering staff following completion of geotechnical and hydrological studies. The design of cofferdams is beyond the scope of this manual. However, the following are some considerations:

- If no dewatering is needed, the material used for cofferdams should be clean granular material without a significant silt or clay content. Since the material may be excessively permeable, a geotextile may be needed to contain sediment produced by the instream construction

- The instream constriction caused by the cofferdam should not be large enough to produce unacceptable scour velocities in the remaining channel section
- Where possible, cofferdams should not cause hindrance to the passage of fish or boats
- Cofferdams should be removed as carefully as possible to minimize sediment disturbance.

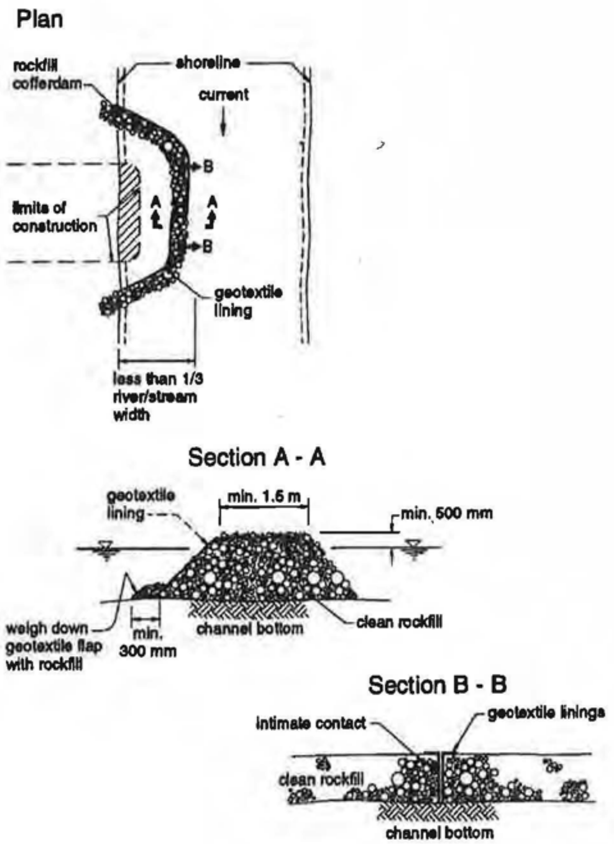


Figure 16 – Geotextile lining on the interior of a rock fill cofferdam

5.1 Cofferdam Lining

In some watercourses, a staked or floating silt barrier will not be feasible due to high flows and current velocities. It may be necessary to construct a semicircle or U-shaped cofferdam lined with geotextile. Construct the cofferdam with either clean, durable rock fill (Figure 16) or large precast concrete blocks.

If the rock fill is uniform and significant flow can occur through the dam, a non-woven geotextile of medium puncture resistance (such as, Terrafix 360 R) can be installed in the dam to better isolate the construction area. Locate the geotextile outside the cofferdam of the upstream half and inside for the downstream half to ensure the current does not easily displace the geotextile. Place geotextile with a short flap (300mm) at the base of the cofferdam, weighted down with clean rock fill.

After construction and sediment in suspension has settled out, it may be necessary to remove the cofferdam, or spread out the rock fill to provide fish habitat. In some cases, the construction and removal of a cofferdam may cause more of a sediment problem than the construction activity the cofferdam is containing. Consult with Ministry of Environment staff to determine whether to remove the rock fill cofferdam or spread it out.

5.2 Water Structures

An alternative for the diversion or containment of water is the use of inflatable plastic bladders called Aqua-Dams or Water Structures. The structures consist of polyethylene tubes that are placed and then pumped full of water (Figure 17).

Customised lengths and heights are available from most manufacturers. Lengths of 15, 30, and 60 m with heights ranging from 0.3 to 2.7 m when filled are standard. Can be installed in either standing or flowing water. However, flowing water does pose problems and may require additional staff, pump capacity, saddle weights to hold it in place, and possibly heavy equipment.

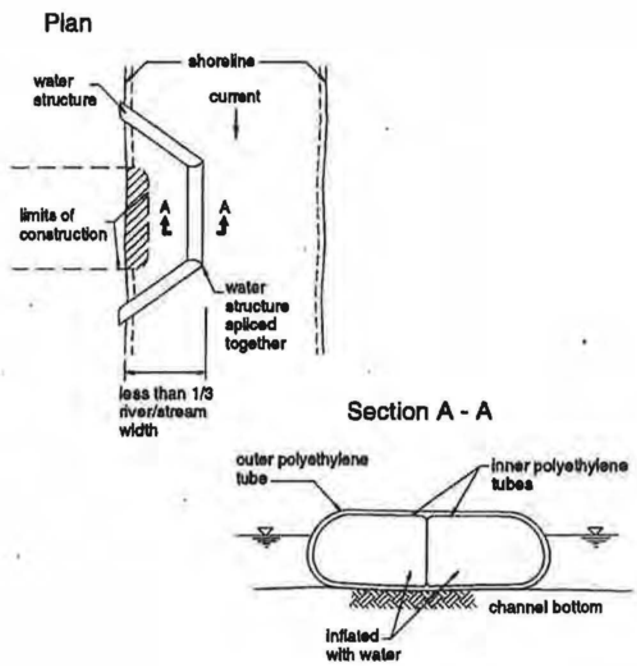


Figure 17 – Water Structure use to isolate a portion of a channel

For size selection and specific installation, maintenance, and removal procedures, follow manufacturer's specifications.

Some factors to consider in determining the feasibility of using water structures are:

- Velocity of water—as the area of flow is reduced, the water velocity will increase. This may cause scouring of the streambed or undermining of the water structure.
- Characteristics of site—due to its flexibility, the water structure will conform to most streambeds when filled. A site that is flat and free of sharp objects, such as, thick branches, deadfalls, sharp rocks, or large debris is best suited for the use of a water structure. Remove large boulders or other obstructions, either by hand or with equipment, to ensure a good seal.
- Small sites—to provide an enclosed area along a shoreline the water structure must take the shape of the site. When flow is negligible and when using small structures, the barrier can be bent to adjust its direction.
- Large sites—Where there is significant flow or where a larger sized barrier is needed, splice or join together the water structure to form the enclosure.
- Changing water levels—spring run-off, local wet seasons, and thunderstorms can affect water levels. Schedule the use of the barrier with favourable construction dates, and consider changes to water levels.

5.3 Staged Construction

Projects that require work across an entire watercourse (e.g., road construction, culvert installation, utility installation, or channel liner replacement) can be carried out using a staged approach:

1. Install the barrier (i.e., cofferdam, staked or floating silt barrier, or water structure) to isolate just over half o the stream channel (Figure 18).
2. Carry out construction in the isolated area (Area A, Figure 18).
3. Dewater enclosed area if necessary. If dewatering is necessary, pay special attention to barrier design.
4. When construction in complete is first area, turbid water or accumulated sediment is removed, remove the barrier and repeat process in Area B.

6 *Instream Weirs*

Use instream weirs to cause settlement of the coarser suspended material. This type of weir is usually constructed of large diameter rock fill placed across the channel. They resemble shallow dams that crest below the water level, and function similarly to check dams or sand traps (Figure 19).

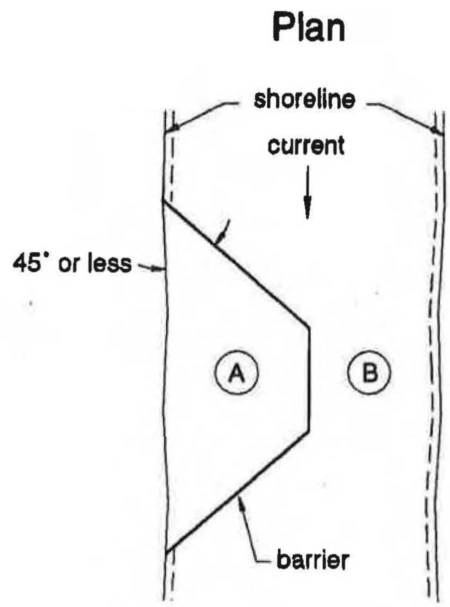


Figure 18 – Staged Construction

6.1 Construction Specifications

1. All weir crest rocks must slope down from the banks to the upstream point of the weir—to confine the flow to the middle 1/3 of the stream—and the rock should extend upstream from each bank to the middle point of the weir to form a "V" shape
2. Place the largest rocks at the point of the weir and set them firmly in place. Jam all rocks together with as tight a fit as possible. Place additional stabilising rocks around these large rocks. The weir crest width should be 1.5m wide.
3. The top of the rocks in the notch in the weir must not be more than 0.6m above the streambed. The bank tie-in must be 1.5m above the stream elevation (above high water).
4. All elevation differences must relate to the low flow conditions (summer or fall).
5. Place riprap downstream of the weir for a minimum distance of 2m, to prevent erosion and possible undermining of the weir.

7 *Isolation of Sensitive Areas*

Silt barriers (staked and floating) are generally used to contain sediment within the construction area. They can be used equally will to protect a sensitive area from sediment and turbidity. For these types of applications, restrict the silt barrier to the configurations and flow conditions described in Sections 4.1 and 4.2.

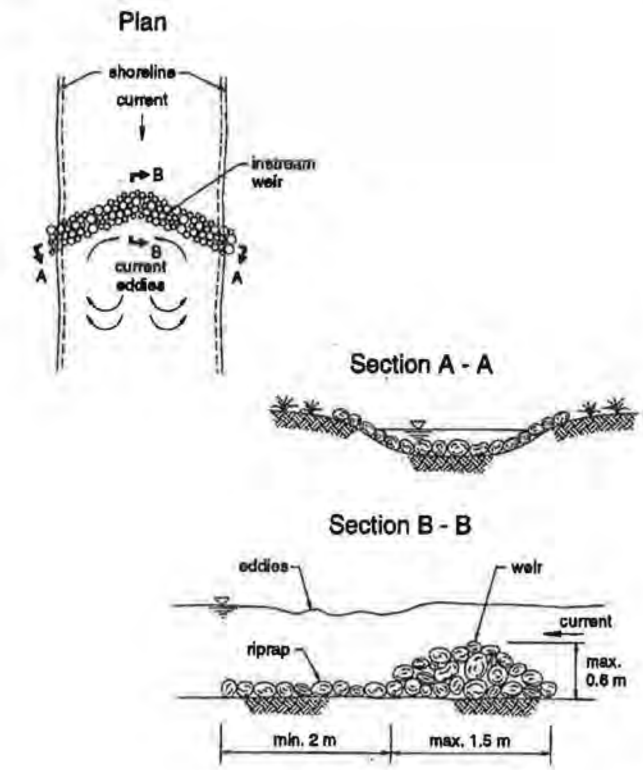


Figure 19 – Typical V-weir configuration

8 *Construction Windows*

A primary method of protecting fish and fish habitat is the careful timing of construction activities. Work windows for Southern Interior[1] (Area 2) species are listed in the following Table 11. Where more than one species is known to be present in a stream, the more restrictive work window may apply. Obtain advice from a Fish & Wildlife biologist for all instream construction projects.

Table 12 – Construction Timing Restrictions[2]

Species Present	Timing Window[3]
Kokanee	May 15 – Aug 31
Steelhead	Jul 15 – Apr 15
Rainbow Trout	Aug 15 – Apr 15
Cutthroat Trout	Aug 15 – Apr 15
Dolly Varden & Bull Trout	Apr 1 – Jul 31
Whitefish	Jun 1 – Sep 15

Notes: 1. *Land Development Guidelines for Protection of Aquatic Habitat*, May 1992.
2. Table A3.1—Fisheries Sensitive Zone Species Timing Windows, *Land Development Guidelines*.
3. Dates may vary for some watercourses. Confirm timing window with staff at Regional office of BC Environment.

9 *Emergency Situations*

9.1 General

Many variables can affect construction instream or next to a watercourse. An unforeseen storm event is the most common complication for instream sediment controls. Extreme storms can cause extensive overland erosion from rainfall impact and storm water run-off. Stream flows also increase, with a corresponding increase in current velocities and water levels. The construction supervisor must be continually aware of current weather predictions and the potential ramifications.

If sediment is accidentally released and may be considered a spill, report to the Ministry of Environment, Lands and Parks at 1-800-461-1127.

9.2 On-Site Materials

Control excessive overland run-off by constructing diversion berms or check dams from rock, soil or concrete blocks.

Additional sediment control or interception methods such as silt fences, or sediment traps may be required. Refer to the City of Kelowna's *Best Management Practices for Erosion and Sediment Control* for detailed guidance and specifications. Maintain an extra supply of these erosion control products and equipment at the site at all times. Observe run-off patterns to discern if placement of additional measures is needed.

9.3 Damage Control

The remedial measures described in this section may be used alone or in conjunction with the other measures described. If failure of the barrier cannot be prevented, suspend construction activities until a suitable sediment control measure can be installed.

In an emergency situation, weigh the benefits of suspending construction activities against the potential for unmitigated damage as a result of leaving an exposed or disturbed site.

Before a silt barrier fails, many steps can be taken to save the installation.

9.3.1 Staked Silt Barriers

During emergent conditions, additional support or protection can quickly be provided to a staked barrier by several methods:

1. Place a log across a small stream and attach the top of the stakes or posts and barrier to the log similar to cable arrangement in Figure 6.
2. Attach anchors or weights as required to the posts or stakes
3. Brace the barrier by placing support posts against the silt barrier
4. Provide rock fill cofferdam immediately upstream and partially around the side of the barrier.

9.3.2 Floating Silt Barriers

Where excessive flows are threatening a floating silt barrier installation, attach additional anchors to the barrier as required. Higher flows can cause the skirt to flare and lift off the channel bottom. Have divers attach additional weights such as concrete blocks along the bottom edge of the barrier with non-corrosive wire.

If rising water levels lift the floating barrier off the bottom, suspend construction operations until the water level lowers, or install a longer barrier.

10 Summary

Consult with Ministry of Environment, Lands and Parks and any other relevant government agency as early as possible when considering any instream construction activity that can potentially cause damage to fish habitat and water quality.

Remember that instream construction requires a great deal of planning to minimize impacts. The provision of silt barriers is only a last resort after location, timing and construction techniques have been established. The goals should be to minimize the amount of instream work required, and to complete the work as quickly and efficiently as possible.

When designed and installed properly, silt barriers can be a very effective means of reducing the amount of soil particles introduced into a watercourse.

It is important that such installations be viewed as isolation techniques, not filtering devices.

11 References

Instream Sediment Control Techniques Field Implementation Manual. Trow Consulting Engineers Ltd. and Ontario Ministry of Natural Resources. (1997).

Department of Fisheries and Oceans, Ministry of Environment, Lands and Parks. *Land Development Guidelines for the protection of Aquatic Habitat.* (1992).

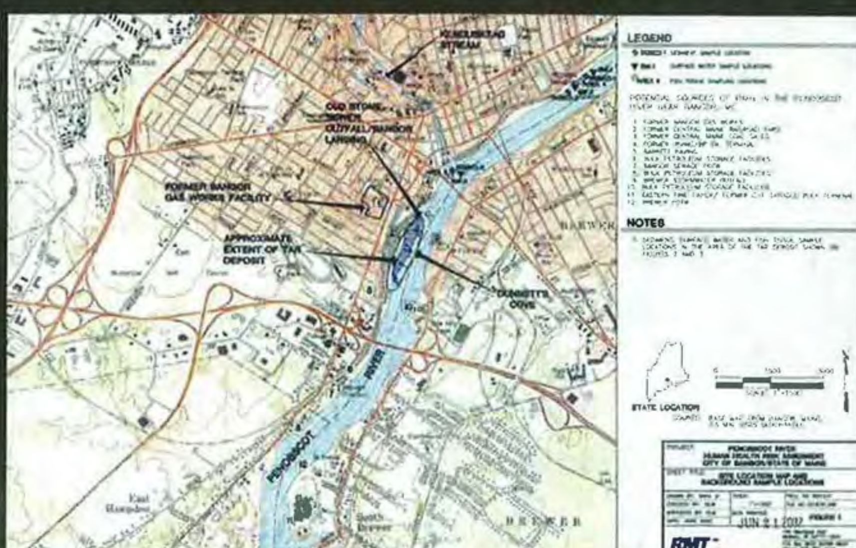
Ministry of Environmental, Land and Parks. *Urban Runoff Quality Control Guidelines for British Columbia.* (1992).

Bangor Landing
Bangor, Maine

Case Study-Sediment Remediation

Maine Department of Environmental Protection
City of Bangor, with RMT, Inc.

Site Location and Local Site Features



Bangor Landing Project Background Summary

- Bangor Gas Works (BGW) operated a manufactured gas plant between 1851 and 1963
- BGW waste water, containing coal tar and oil tar, was discharged to a stone sewer, which then discharged to the Penobscot River
- Tars entrained in warm, fast moving waste water precipitated out upon entry to slower, colder water of Dunnett's Cove
- Tar is present in sediments in Dunnett's Cove over an approximate 11 acre area
- Origin of the tar was explored, and other potential sources were ruled out, BGW is the most likely source of the tar based PAHs in the river
- Source site was remediated by removal/equivalent cap and the parcel returned to productive use as a grocery store site

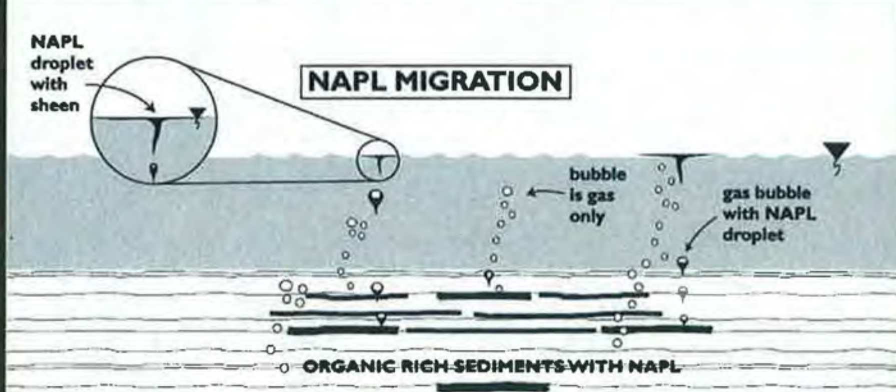
Tar and Sheen on River Surface

At low tide in warm weather, tar moves to surface of the river from tar deposit near the sewer, and is transported by river currents

Remedial Investigation

- Sediment, Surface Water, Fish Tissue Characterization-2002-2003
- HHRA/BERA-2002, 2004
- Remedial Action Objective-2005
- Feasibility Study-2005
- Pre-Design Studies 2007-2008
  - Bathymetry
  - Hydrodynamics and tidal flux
  - Groundwater interaction
  - Ice impact study
  - Geotechnical Investigation
  - Waterway use and infrastructure

Gas from Sediment Brings Tar to Water Surface



NAPL migrates to surface from sediment. Transport is facilitated by gas migrating from the sediment.

Figure by RMT, Inc.

Longitudinal Cross Section of Tar Deposit

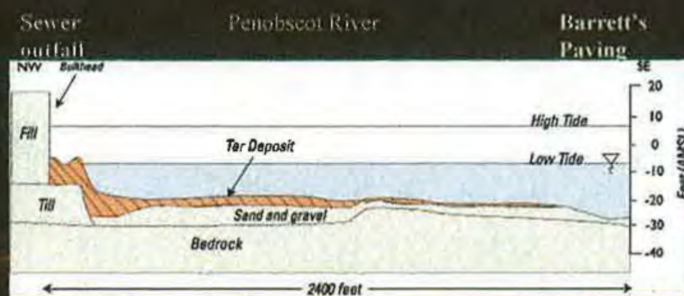


Figure by RMT, Inc.

Tar deposit thickest near sewer outfall (14 ft) and thins downstream
(4 ft thick 1,000 feet from sewer outfall)

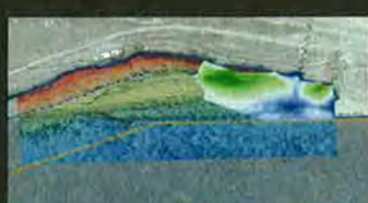
Findings

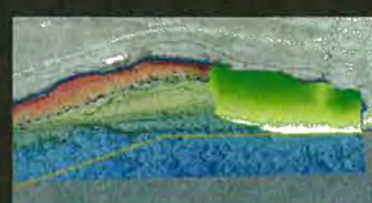
- human health/eco risk from PAHs, including benzo (a) pyrene
- ~11 acre tar deposit in sediment
- tar within the deposit is more mobile at upper end of the cove, more weathered at lower end of the cove
- Three remedial action areas
  - Primary Active Zone (PAZ)
  - Secondary Active Zone (SAZ)
  - Inactive Area

Selected Remedy

- risk based cleanup
  - Removal-stabilization and disposal of mobile source areas, source reduction
  - Cap remaining PAH areas in the PAZ, SAZ
  - Habitat cover over weathered tar to enhance natural sedimentation and natural re-colonization

Dredge and Cap-Primary Active Area





Figures by RMT, Inc.

The Modified Remedy for the PAZ includes the following components:

Limited remedial dredging – Approximately 6,000 to 8,000 cubic yards of sediment will be mechanically dredged from the PAZ, in order to create grades appropriate for construction of a NAPL Trapping Cap, and to perform source reduction in the areas of the "Tar Puddle" and tar rivulets. The dredging will also reduce the overall mass of tarry sediment and will increase the permanence of the remedy.

NAPL Trapping Cap (patent pending) – Following the completion of dredging, a NAPLTrapping Cap (patent pending) will be constructed, which will consist of a gas transmission zone (permeable materials), a gas control zone (impermeable materials), and armor stone, which will be sloped toward shore in order to guide migrating gas and tar to a near shore vent area where the tar will be trapped and the gas will be released to the atmosphere.

Considerations for Dredging Remedy

- Access, navigational traffic
- Background/downstream TSS
- Buried debris/boulders
- Currents/tides
- Dredging depths, side slopes
- Slope stability at shoreline, navigational channel
- Work area, sediment handling area
- Transport routes
- Endangered species considerations
  - Atlantic salmon
  - Short nosed sturgeon

Considerations for Capping Remedy

- Water depths/slopes
- Slope stability, erosion
- Currents, tides
- Access and navigation demands
- Groundwater flow
  - Seepage/upwelling
- Sediment gas

Site Preparation

- Install H-piles, dolphin piles
- Erect stabilization building, build stabilization pit
- Construct crane pad
- Move barge into place
- Install turbidity/fish curtain
- Stabilize Bulkhead - Install pins
- Manufacture Aquablok

Sediment Dredging

- Primary Active Zone (PAZ) ~ 1.3 acres
- Total Volume Tar Impacted Sediment – 21,000 cubic yards
- Sediment Dredged ~ 7,000 cubic yards (approx 100,000 gal NAPL)
- Stabilized Sediment Disposed ~9,500 tons

Stabilize Dredged Sediment

Lessons Learned-Dredging Operation

- Double boom often necessary to contain NAPL, turbidity
- Tide cycle proved very limiting to use of long arm excavator
- Uneven dredge surface made survey difficult
  - In field efforts to smooth cap layers
    - Crane bucket drag
    - I-beam rake

Yes

1-6

Field Change Orders – Design Changes

Modified dredge depths

- Modified cap design
  - Tapered design at bulkhead
  - Change to toe of slope, toe vent
  - Change to design grades
  - Change to OSSO invert
- Changes to materials specifications
  - Substitute select stone for general fill
  - Fines in riprap
  - Change in Aquablok design mix production, storage, placement
  - Lime instead of QuickSolid50 as stabilizing agent
- Discontinue air monitoring
- Discontinue turbidity monitoring, remove turbidity curtain
- Remove temporary settlement plates from plan
- Modify construction quality control program

Lessons Learned-Cap Construction

- Barge-based install uneven surface made survey difficult
  - In field efforts to smooth cap layers
    - Crane bucket drag
    - I-beam rake
- Ice, tides hampered near shore construction
- Silt curtain trapped ice, ice flow tore at curtain
- Rock dust turbidity bigger problem than dredging
- Flexibility and teamwork to resolve issues is key to successful project

Containment Around Construction Area

Slide content courtesy of RMT, Inc

Lessons Learned

- Endangered species consideration restricted construction schedule, short days and unfavorable tides meant occasional night work
- Night work meant no survey data collected
- Late fall through winter construction meant flooding conditions, ice

Next Steps

- Complete construction tasks
  - gas collection trench
  - OSSO invert
  - re-survey
- Cap performance monitoring program
  - Visual observation of ebullition, tar
  - Tar flux evaluation
  - Piezometer measurements, pore water sampling
  - Observation tubes
  - Monitor vapor points at shoreline
  - Visual inspections
    - Near shore
    - Intertidal
    - Ice evaluation
    - Subtidal
  - Settlement plates

Project Team

- City of Bangor
  - Jim Ring, Director Engineering and Infrastructure
- RMT, Inc.
  - Gene McLinn - Project Manager
  - John Rice, Hans Hinke – Design, Project Engineers
- Maine Department of Environmental Protection
  - Kathy Howatt – Project Manager
  - Troy Smith – Project Geologist
  - Fred Lavallee – Project Engineer
- MACTEC Engineering and Consulting – project overseer for DEP

NAPL Trapping Cap Design contact information

RMT, Inc.
744 Heartland Trail
Madison, Wisconsin 53717
608-831-4444

Gene McLinn
[redacted]

John Rice
[redacted]

Cap Installation

- cap installed in layers
  - cast with long arm excavator
  - dropped with crane bucket
  - cast with stone slinger
- each layer surveyed
- Layers "stepped" to avoid butt end joins

Cap Installation Cross Section

Placing Gas Transmission (A) & Control Layers (B), Armor (C) in Intertidal Zone

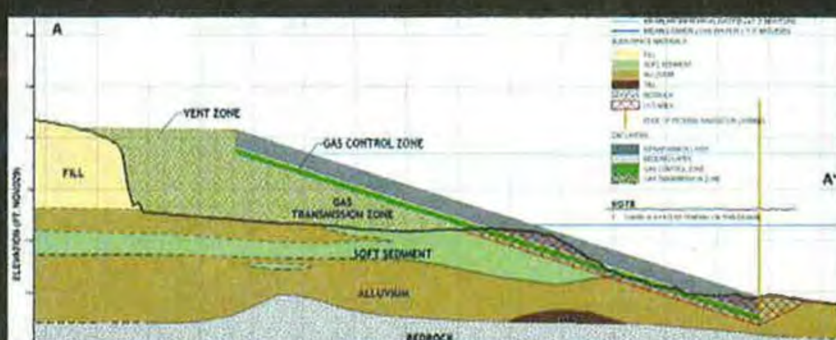
Slide content courtesy of RMT, Inc

Lessons Learned - Stabilization

- Spec'd stabilization agent QuickSolid 50 ineffective
- Lime as a stabilizing agent created unregulated airborne dust– applied 20% opacity not to exceed standard
- Water spray for dust control generated high pH surface water runoff
- Air scrubber system, installed to handle VOCs, not needed and not applicable to lime dust
- Water handling system, installed to de-water sediment for stabilization, not needed
- Odor control not needed

Remedial Cap Design Components

Cross Section of NAPL Trapping cap



- Vent the gas, trap tar, transmit water
- Patent pending

Slide content courtesy of RMT, Inc

Coffer Dams

Sediment Control

BMP30

MTO Developed/Adopted References for Contract

O.P.S.S.:	517, 518, 577
O.P.S.D:	219.260
S.P.:	577F02
N.S.S.P:	

Adapted from "National Guide to Erosion and Sediment Control on Roadway Projects", Transportation Association of Canada, 2005

Coffer Dams

Sediment Control

BMP30

Description and Purpose

- A temporary dam constructed of earth, sheet piling or other material to enclose a work area and permit the removal of water
- Portable fabric cofferdams may be considered for use in Ontario
- To isolate equipment, materials and operations

Applications

- Work areas that encroach into a watercourse, lake, or wetland
- Areas where the coffer dam will not hinder passage of fish and brats

Advantages

- Permits work to be carried out in the dry
- Allows boat and fish passage
- Does not unduly affect flow in the stream

Limitations

- * in areas of shallow flow depth (less than 1.5 m)
- Constant pumping may be required to keep work area dewatered

Construction

- Encroachment into watercourse should be minimized
- Coffer dam should not cause unacceptable sewer and flow velocities in the watercourse
- Height of the dam should provide protection for a 10 year event, if possible (height of dam to be less than 1.5 m)
- All debris and accumulated sediment must be cleared away before removal of the coffer dam
- Operations within the work area must be capable of withstanding inundation without risk to life and equipment damage

Inspection and Maintenance

- Dams should be inspected regularly and immediately repaired if required. A through inspection should be conducted following flood events
- Water removed from work area may be silty and should be discharged to a vegetated area at least 30 m from the watercourse, or pumped through a filter bag
- The weather forecast should be monitored to anticipate the occurrence of high flow events. Work operations should be adjusted to accumulate possible overtopping of the coffer dams

  - Bedding can be comprised of well graded sand and gravel or non-woven geotextile
  - Acts as separating filter between fine grained subgrade and riprap size energy dissipator material
- Place energy dissipator material (rip rap, gravel, sand bags, concrete) over filtration bedding material
  - Top of energy dissipator should be flush with surrounding grade

Construction Considerations

- Length of energy dissipator (La) at outlets shall be of sufficient length to dissipate energy
  - La = 4.5 x D (where D is the diameter of the pipe or channel at the outlet)
  - Energy dissipator should extend upstream of the outlet approximately a minimum distance of 0.5 x D
- Width of energy dissipator (Wa) at outlets shall be of sufficient width to dissipate energy
  - Wa = 4 x D
- Thickness of energy dissipator (da) at outlets shall be of sufficient thickness to dissipate energy
  - da = 1.5 x maximum rock diameter (with a minimum thickness of 0.30 m)
- Energy dissipator (splash pad, apron) shall be set at zero grade and aligned straight, with the direction of flow at the outlet
- Bedding (filtration) layer can comprise either non-woven geotextile or a minimum of 0.15 m well graded sand and gravel layer
- Energy dissipator should be constructed of well-graded rip rap
  - Minimum d50 = 150 mm. Preferable d50 = 300 mm
  - Minimum thickness = a) 1.5 x d50 or b) 0.30 m to 0.45 m thickness. (a or b whichever is greater)
- Energy dissipator shall be designed to accommodate a 10-year peak runoff or the design discharge of the upstream channel, pipe, drain, or culvert, whichever is greater

Inspection and Maintenance

- Periodic inspections to check for damage should occur at least once a month, or after storm events (1:2 year storm and/or 40 mm rainfall over 24 hour duration)
- Any damage should be repaired immediately

Similar Measures

- Gabion mattresses

Energy Dissipators

Erosion Control

BMP31

Description

- Minimizes scour at flow impact location with dissipated flow energy
- Hard armour (rip rap, gravel, sand bags, concrete) placed at pipe outlets, in channels and downstream of check structures to reduce velocity and dissipate energy of concentrated flows
- Standard drain trough terminal protection structure generally used on bridge headslopes

Applications

- Permanent measure
- May be used at outlets of pipes, drains, culverts, conduits, or channels with substantial flows
- May be used at slope drain outlets located at the bottom of mild to steep slopes
- May be used where lined channels discharge into unlined channels
- May be used as a splash pad downstream of gabions, check structures, berms, barriers, and silt fences to prevent erosion caused by overtopping

Advantages

- Reduces flow energy in a relatively small area

Limitations

- Small rocks or stones can be dislodged during high flows
- Grouted rip rap may break up due to hydrostatic pressure, frost heave, or settlement
- May be expensive if construction materials (rip rap, gravel, or concrete) are not readily available
- May be labour intensive to place and construct
- Extreme flow velocities may require paved outlet structures, stilling basins, plunge pools, drop structures, baffles, or concrete splash pads which will require special design by qualified personnel. Energy dissipators constructed of rip rap may not be adequate for extreme flow velocities

Construction

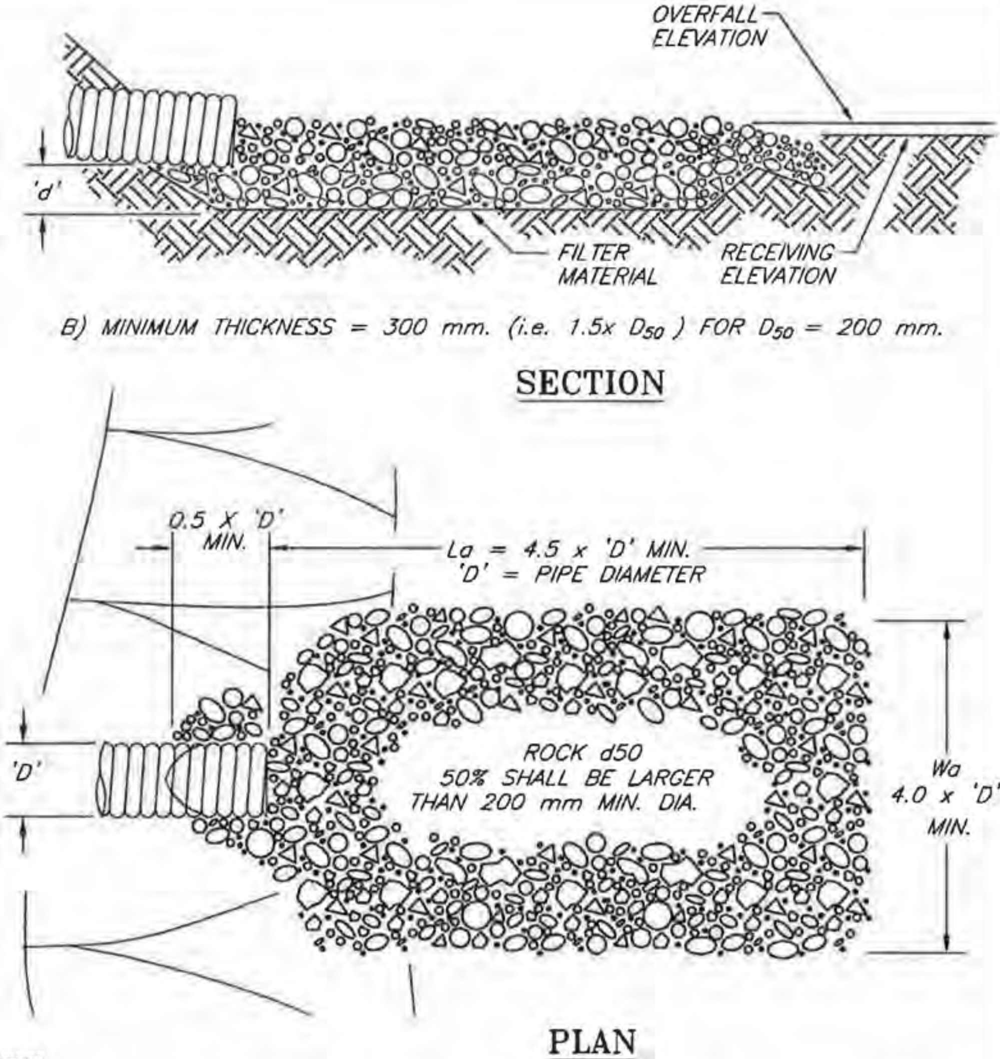
(Note: The following method is provided for guidance only. A site-specific design by a qualified designer is required.)

- Grade the area to final design grades and elevations
- Sub-excavate energy dissipator location to thickness of energy dissipator
- Place filtration bedding material on base of excavation

Energy Dissipators

Erosion Control

BMP31



NOTES:

1. 'La' = LENGTH OF APRON. DISTANCE 'La' SHALL BE OF SUFFICIENT LENGTH TO DISSIPATE ENERGY.
2. APRON SHALL BE SET AT A ZERO GRADE AND ALIGNED STRAIGHT.
3. FILTER MATERIAL SHALL BE FILTER FABRIC OR 150 mm THICK MINIMUM GRADED GRAVEL LAYER.
4. FOR PIPE DIAMETER > 600 mm, DESIGN BY ENGINEER IS REQUIRED.
5. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

ENERGY DISSIPATOR FOR CULVERT OUTLET

FILE: ENRGYDIS

Energy Dissipators

Erosion Control

BMP31

MTO Developed/Adopted References for Contract

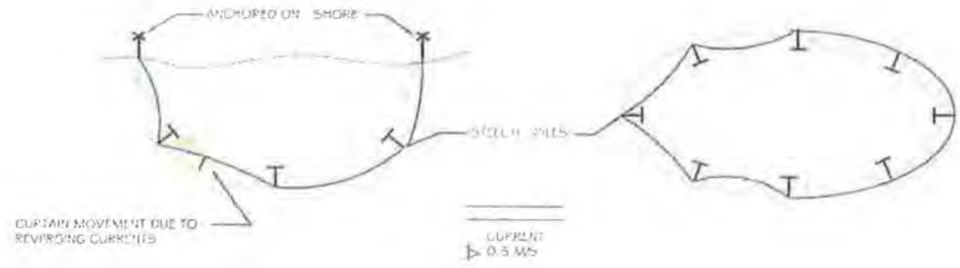
O.P.S.S.:	904
O.P.S.D.:	804.04
S.P.:	904S11
N.S.S.P.:	

Adapted from "National Guide to Erosion and Sediment Control on Roadway Projects", Transportation Association of Canada, 2005

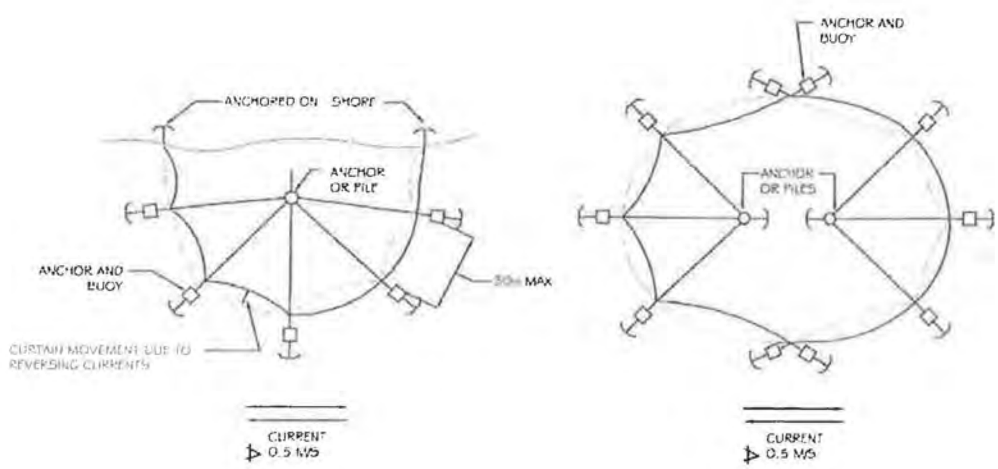
Turbidity Curtains

Sediment Control

BMP32



(A) WITH PILES



(B) WITH MARINE ANCHORS

TYPICAL SILT CURTAIN DEPLOYMENT CONFIGURATIONS

Turbidity Curtains

Sediment Control

BMP32

Description and Purpose

- A geotextile barrier installed in a slowly flowing, or quiescent, river, lake, or wetland to contain suspended sediment produced by construction
- In shallow water the curtain may be mounted on posts driven into the bed. In deeper systems the curtain may be suspended from ropes supported by floats (and suitably anchored).

Applications

- For use in a slowly flowing river, lake or wetland
- Where there are fine sediments that have long settling times

Limitations

- Not feasible in higher currents (greater than 0.5 m/s)
- Not feasible in higher or breaking wave conditions
- Not feasible in the presence of ice

Construction Considerations

- The curtain should be installed according to manufacturer's and/or MTO specifications
- The curtain should not be removed until all construction activity has been completed and all suspended sediment has settled

Inspection and Maintenance

- Turbidity curtains are vulnerable to damage from wind, waves, currents, ice and boats, and should therefore be monitored regularly (and especially after storm events) to ensure that the curtain is functioning satisfactorily

MTO Developed/Adopted References for Contract

O.P.S.S.:	577
O.P.S.D:	219.260, 219.261
S.P.:	577S01, 577F01
N.S.S.P:	

Adapted from "National Guide to Erosion and Sediment Control on Roadway Projects", Transportation Association of Canada, 2005

Drain Inlet Sediment Barrier

Sediment Control

BMP33

Construction

(Note: The following method is provided for guidance only. A site-specific design by a qualified designer is required.)

- Place inlet sediment barrier around entrance to drain/pipe. The option appropriate for use is dependent on site conditions.
- Silt fence barrier can be used for soil surfaces
- Gravel or aggregate filled sand bags should be used for asphalt or concrete surfaces
- Aggregate filled sand bags
  - Place sand bags stacked one or two bags high around inlet
- Gravel barriers
  - Place concrete blocks stacked one or two blocks high, with cavities of blocks aligned with direction of flow, around inlet
  - Wrap 13 mm wire mesh around concrete blocks
  - Place 25 mm to 38 mm diameter rock around block and wire mesh assembly ensuring rock extends down from top of blocks to asphalt or concrete surfacing
- Gravel filter curb inlet
  - Place concrete blocks stacked one or two blocks high around inlet, with cavities of blocks aligned with direction of flow, forming a 'U' shape
  - Wrap 13 mm diameter wire mesh around concrete blocks
  - Place 25 mm to 38 mm diameter rock around block and wire mesh assembly ensuring rock extends down from top of blocks to asphalt or concrete surfacing

Construction Considerations

- Gravel or aggregate filled sand bags should be used for asphalt or concrete surfaces
- Aggregate filled sand bags
  - Sand bags should be filled with pea gravel, drain rock, or other free draining material
  - Gravel or aggregate filled sand bags should be filled only three-quarters full to allow sand bag to be flexible to mould to contours, maintaining continuous contact with surface
  - Barrier should be placed at least 0.1 m from inlet to be protected
  - Several layers of sand bags should be overlapped and tightly packed against one another
  - A one sand bag wide gap should be left in the lowest point of the upper layer to act as an emergency spillway
- Gravel filter inlet berm and gravel filter curb inlet
  - Slope gravel towards inlet at a maximum slope of 2H:1V
  - Maintain at least 0.3 m spacing between toe of gravel and inlet to minimize gravel entering inlet
  - 25 mm wire mesh may be placed over inlet to prevent gravel from entering the inlet

Drain Inlet Sediment Barrier

Sediment Control

BMP33

Description and Purpose

- Temporary devices constructed to minimize the amount of sediment entering a storm drain by ponding sediment laden runoff at the inlet
- Storm Drain Inlet protection can consist of the following measures:
  - Block and Gravel Sediment Barrier – Option 1
  - Block and Gravel Curb Inlet Sediment Barrier – Option 2
  - Sand Bag Curb Inlet Sediment Barrier – Option 1
  - Sand Bag Curb and Gutter Sediment Barrier – Option 2
  - Silt Fence Sediment Barrier

Applications

- Temporary measure
- Used where storm drains are operational prior to establishing vegetation on disturbed drainage areas
- Can be effective where drainage enters municipal sewers or watercourses
- Used for small, nearly level (less than 5% grade) drainage areas
- Used as curb inlet barriers in gently sloping ditches and gutters
- Used where drainage area is 0.4 ha or less
- Used in open areas subjected to sheet flow and concentrated flows less than 0.014 m^3/s
- Block and gravel bag barriers are applicable when sheet flows or concentrated flows exceed 0.014 m^3/s and is necessary to allow for overtopping to prevent flooding
- Excavated drop inlet sediment traps are appropriate where relatively heavy flows are expected and overflow capacity is required

Advantages

- Easy to install and remove
- Sand bags may be reusable

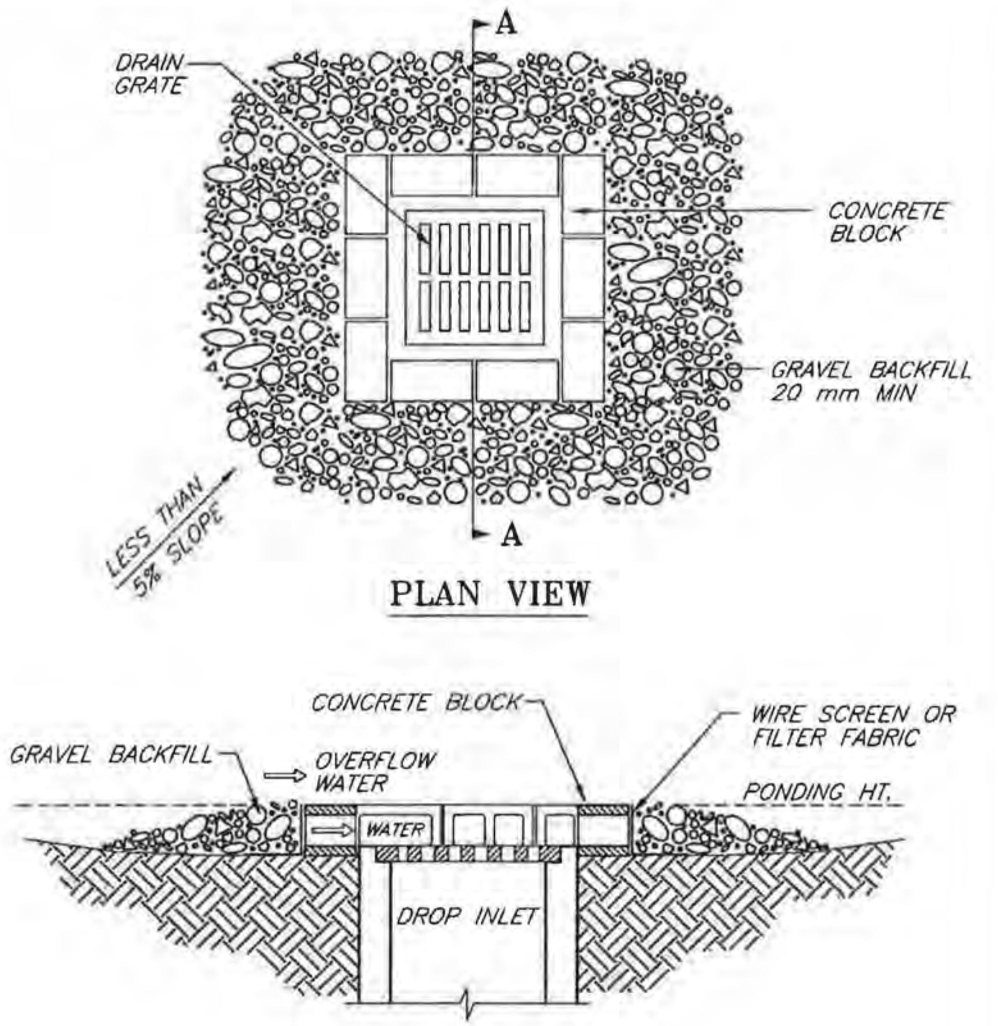
Limitations

- Ponding around inlet may result in local flooding
- Use only when ponding will not encroach into vehicular traffic, onto erodible surfaces and slopes or beyond the limits of the construction site
- Frequent removal of sediment may be required for high flow situations

Drain Inlet Sediment Barrier

Sediment Control

BMP33



NOTES:

1. STORM DRAIN DROP INLET SEDIMENT BARRIERS ARE TO BE USED FOR SMALL, NEARLY LEVEL DRAINAGE AREAS. (LESS THAN 5%).
2. EXCAVATE A BASIN OF SUFFICIENT SIZE ADJACENT TO THE STORM DRAIN DROP INLET.
3. THE TOP OF THE STRUCTURE (PONDING HEIGHT) MUST BE WELL BELOW THE GROUND ELEVATION DOWNSLOPE TO PREVENT RUNOFF FROM BYPASSING THE INLET. A TEMPORARY DYKE MAY BE NECESSARY ON THE DOWNSLOPE SIDE OF THE STRUCTURE.
4. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

STORM DRAIN DROP INLET SEDIMENT BARRIER
(BLOCK AND GRAVEL – OPTION 1)

FILE: BGSEDBAR

Drain Inlet Sediment Barrier

Sediment Control

BMP33

- For drainage areas larger than 0.4 ha runoff should be directed towards a sediment retention device designed for larger flows before allowing water to reach inlet protection structure
- Use aggregate sand bags filled with 25 mm diameter rock in place of concrete
- blocks for gravel filter inlet berm or gravel filter curb inlet

Inspection and Maintenance

- Inspect barriers at least once a week and before and after each significant rainfall event (1:2 year storm and/or 40 mm in a 24 hour period)
- Remove sediment build up after each storm event
  - Sediment and gravel should not be allowed to accumulate on roads
- Replace gravel if it becomes clogged with sediment
- Remove all inlet protection devices when inlet protection is no longer required

MTO Developed/Adopted References for Contract

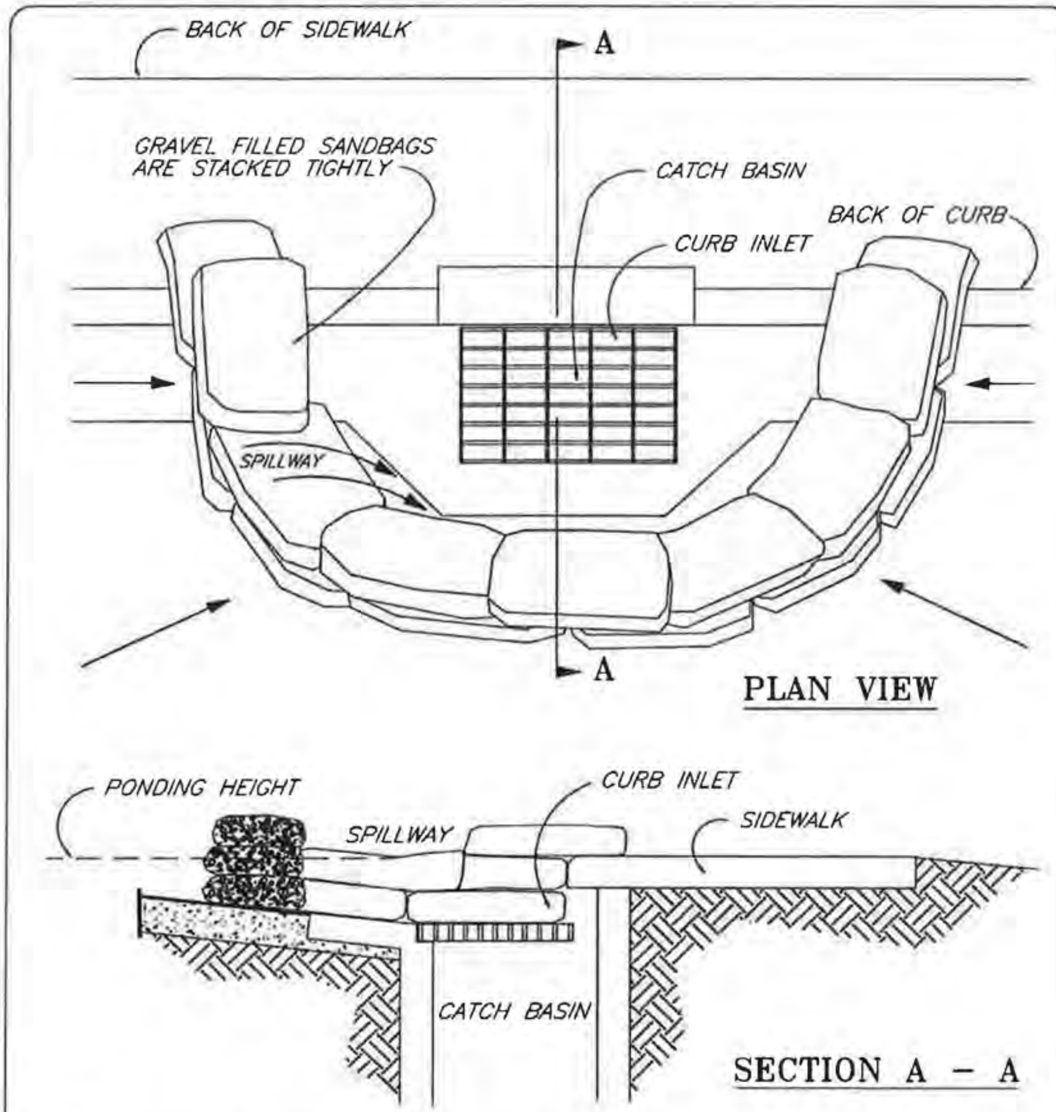
O.P.S.S.:
O.P.S.D.: 219.101 (MTOD)
S.P.:
N.S.S.P.:

Adapted from "National Guide to Erosion and Sediment Control on Roadway Projects", Transportation Association of Canada, 2005

Drain Inlet Sediment Barrier

Sediment Control

BMP33



NOTES:

1. *PLACE CURB TYPE SEDIMENT BARRIERS ON GENTLY SLOPING STREET SEGMENTS WHERE WATER CAN POND AND ALLOW SEDIMENT TO SEPARATE FROM RUNOFF.*
2. *SANDBAGS, OF EITHER BURLAP OR WOVEN GEOTEXTILE FABRIC, ARE FILLED WITH GRAVEL, LAYERED AND PACKED TIGHTLY.*
3. *LEAVE ONE SANDBAG GAP IN THE TOP ROW TO PROVIDE A SPILLWAY FOR OVERFLOW.*
4. *INSPECT BARRIERS AND REMOVE SEDIMENT AFTER EACH STORM EVENT. SEDIMENT AND GRAVEL MUST BE REMOVED FROM THE TRAVELED WAY IMMEDIATELY.*
5. *THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.*

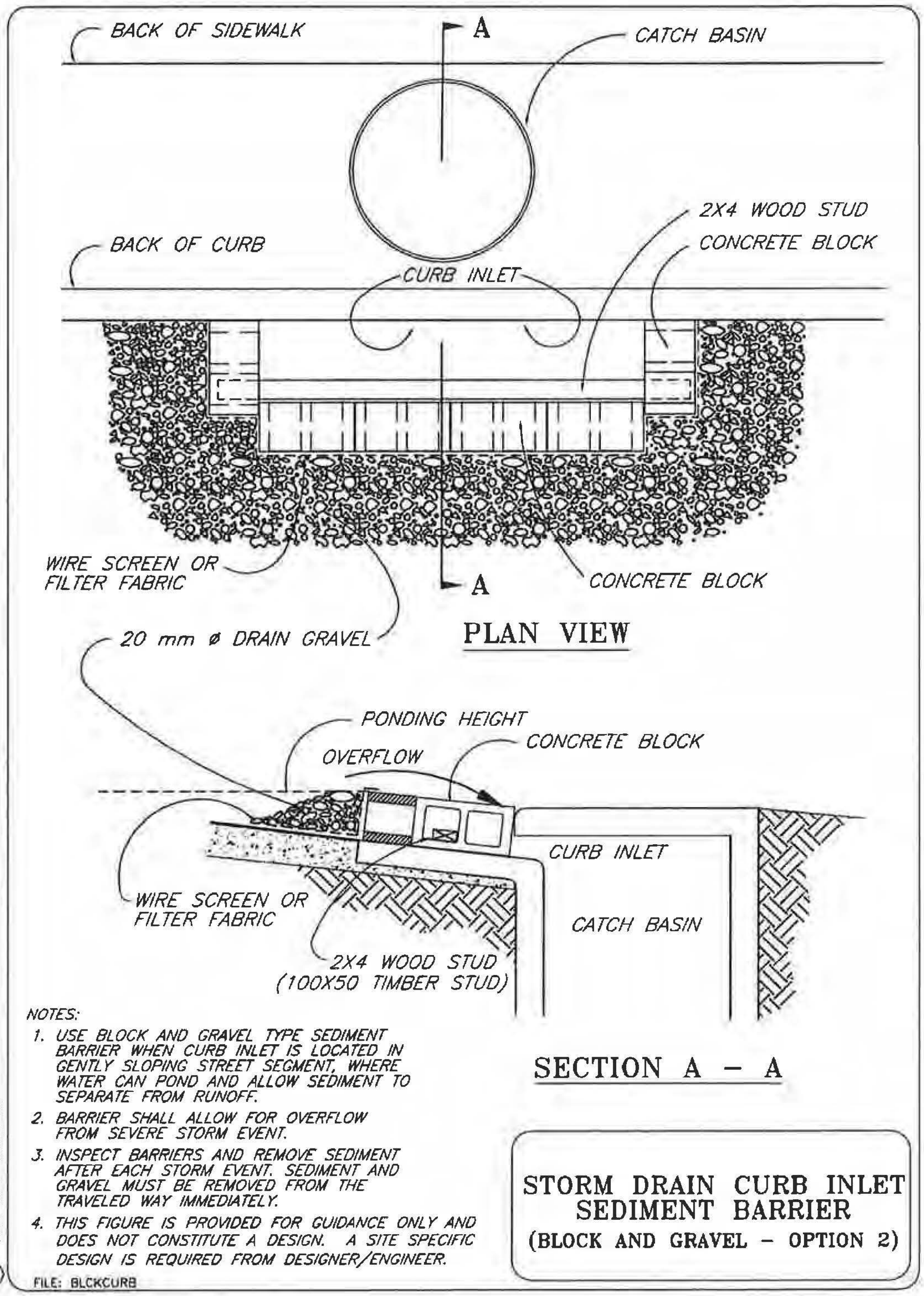
STORM DRAIN CURB INLET SEDIMENT BARRIER
(SANDBAGS – OPTION 1)

FILE: SANDCURB

Drain Inlet Sediment Barrier

Sediment Control

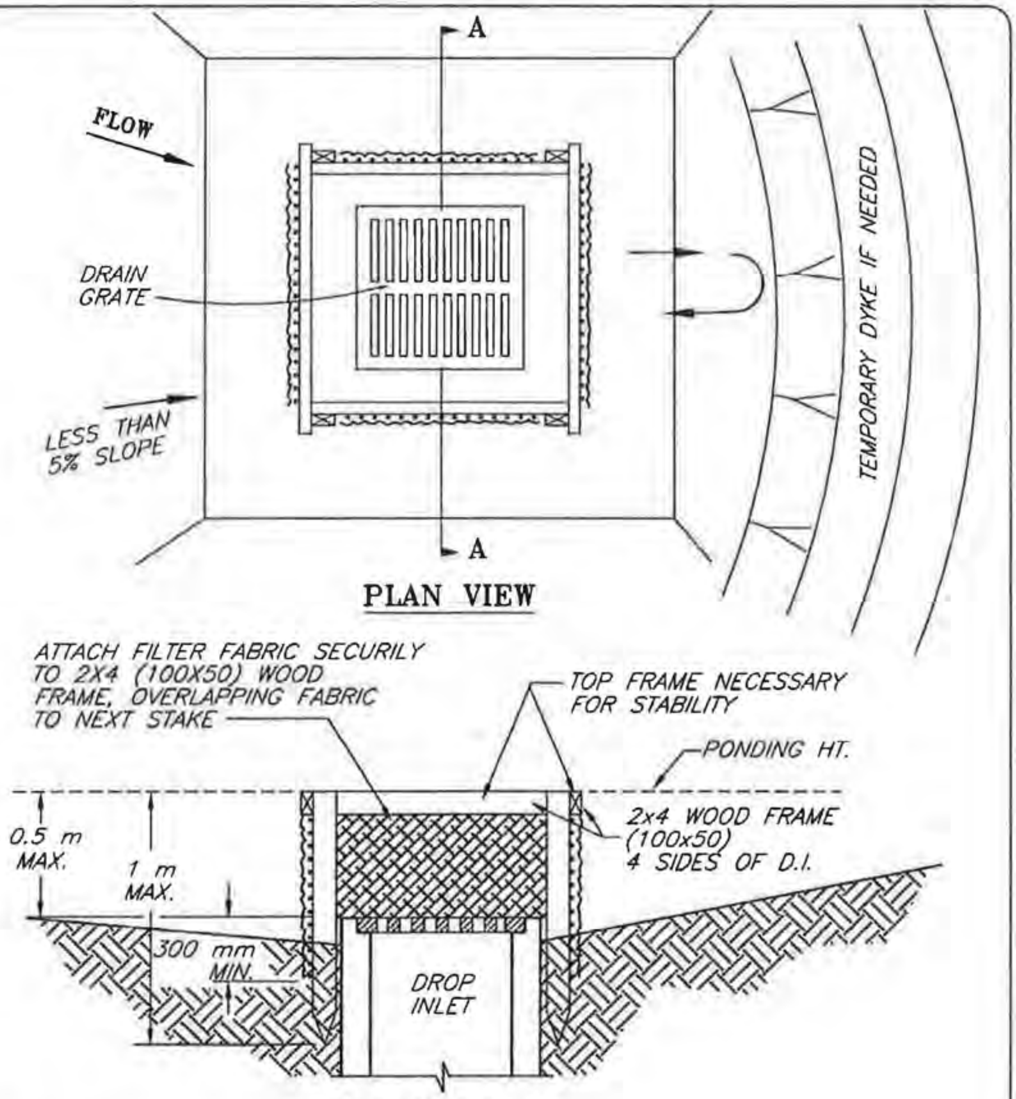
BMP33



Drain Inlet Sediment Barrier

Sediment Control

BMP33



NOTES:

1. DROP INLET SEDIMENT BARRIERS ARE TO BE USED FOR SMALL, NEARLY LEVEL DRAINAGE AREAS. (LESS THAN 5%)
2. USE 2"X4" (100X50mm) WOOD OR EQUIVALENT METAL STAKES, 1 m MINIMUM LENGTH.
3. INSTALL 2"X4" (100X50mm) WOOD TOP FRAME TO INSURE STABILITY.
4. THE TOP OF THE FRAME (PONDING HEIGHT) MUST BE WELL BELOW THE GROUND ELEVATION DOWNSLOPE TO PREVENT RUNOFF FROM BY-PASSING THE INLET. A TEMPORARY DYKE MAY BE NECESSARY ON THE DOWNSLOPE SIDE OF THE STRUCTURE.
5. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

FILE: SILTFDIB

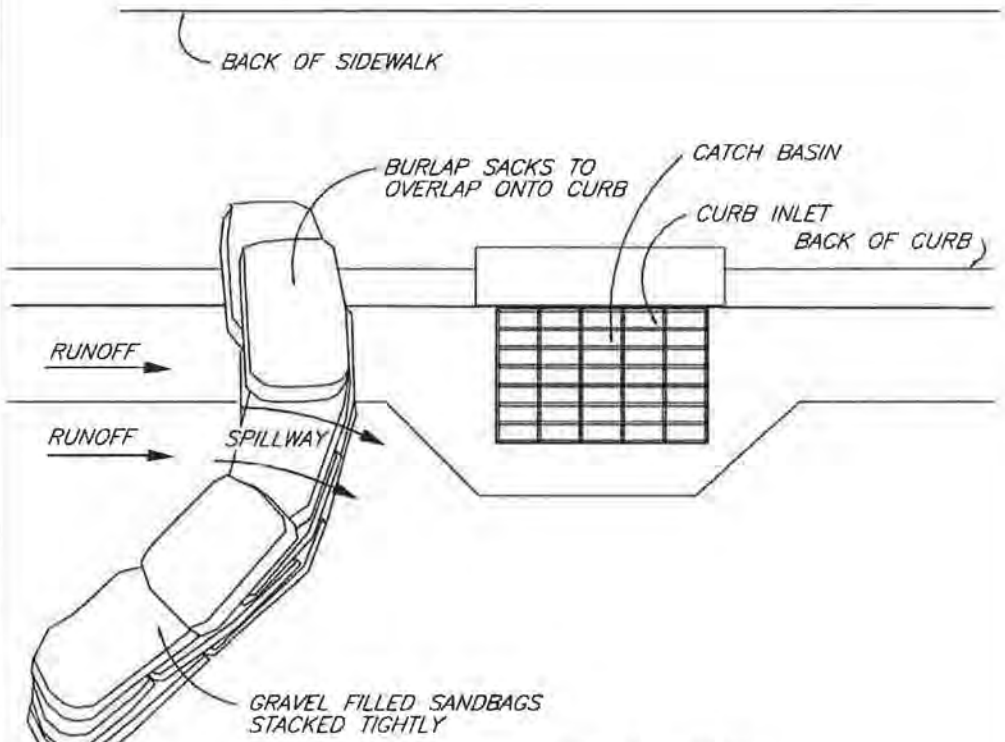
NOT TO SCALE

STORM DRAIN DROP INLET SEDIMENT BARRIER
(SILT FENCE – OPTION)

Drain Inlet Sediment Barrier

Sediment Control

BMP33



PLAN VIEW

NOTES:

1. PLACE CURB TYPE SEDIMENT BARRIERS ON GENTLY SLOPING STREET SEGMENTS, WHERE WATER CAN POND AND ALLOW SEDIMENT TO SEPARATE FROM RUNOFF.
2. SANDBAGS OF EITHER BURLAP OR WOVEN 'GEOTEXTILE' FABRIC, ARE FILLED WITH GRAVEL, LAYERED AND PACKED TIGHTLY.
3. LEAVE A ONE SANDBAG GAP IN THE TOP ROW TO PROVIDE A SPILLWAY FOR OVERFLOW.
4. INSPECT BARRIERS AND REMOVE SEDIMENT AFTER EACH STORM EVENT. SEDIMENT AND GRAVEL MUST BE REMOVED FROM THE TRAVELED WAY IMMEDIATELY.
5. DESIGN CENTRE SPILLWAY LOWER THAN OUTSIDE EDGE TO MINIMIZE FLOW OUTFLANGING.
6. THIS FIGURE IS PROVIDED FOR GUIDANCE ONLY AND DOES NOT CONSTITUTE A DESIGN. A SITE SPECIFIC DESIGN IS REQUIRED FROM DESIGNER/ENGINEER.

STORM DRAIN INLET
CURB AND GUTTER
SEDIMENT BARRIER
(SANDBAGS – OPTION 2)

FILE: CURBGTTR

ASSESSMENT AND REMEDIATION OF CONTAMINATED SEDIMENTS (ARCS) PROGRAM

REMEDIATION GUIDANCE DOCUMENT

Great Lakes National Program Office
U.S. Environmental Protection Agency
77 West Jackson Boulevard
Chicago, Illinois 60604-3590

DISCLAIMER

ACKNOWLEDGMENTS

This report was prepared by the Engineering/Technology Work Group (ETWG) as part of the Assessment and Remediation of Contaminated Sediments (ARCS) Program. Dr. Stephen Yaksich, U.S. Army Corps of Engineers (Corps) Buffalo District, was chairman of the ETWG. Mr. Jan Miller of the Corps North Central Division coordinated the preparation of this report and was the technical editor. Mr. Ojas Patel, of the Corps North Central Division, contributed editing and technical support throughout the production of the document.

The ARCS Program was managed by the U.S. Environmental Protection Agency (USEPA), Great Lakes National Program Office (GLNPO). Mr. David Cowgill and Dr. Marc Tuchman of GLNPO were the ARCS Program managers. Mr. Stephen Garbaciak of GLNPO was the technical project manager and project officer for this project.

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Principal authors of chapters of this document were:

Chapter 1 *Jan Miller*, Corps North Central Division
Chapter 2 *Jan Miller*
Chapter 3 *Michael Palermo*, Corps Waterways Experiment Station
Chapter 4 *Donald Hughes*, Hughes Consulting Services/Great Lakes United
Chapter 5 *Paul Zappi*, Corps Waterways Experiment Station
Chapter 6 *Donald Hughes* and *James Allen*, Bureau of Mines Salt Lake City Research Center
Chapter 7 *Daniel Averett*, Corps Waterways Experiment Station
Chapter 8 *Jan Miller*
Chapter 9 *Donald Hughes* and *Trudy Olin*, Corps Waterways Experiment Station

The original enclosed dredge bucket (Figure 4-2) features covers designed to prevent material from spilling out of the bucket while it is raised through the water column. The design also employs rubber gaskets or tongue-in-groove joints that reduce leakage through the bottom of the closed bucket. An alternative design, developed by Cable Arm, Inc. (Figure 4-2), offers several advantages over the standard clamshell design, including the ability to remove sediment in layers, leaving a flat sediment surface.

Enclosed bucket dredges have been used routinely in various Great Lakes ports for the maintenance of navigation channels. They have also been used in sediment remediation projects in the Black River near Lorain, Ohio, in 1990, and in the Sheboygan River, Wisconsin, in 1990 and 1991. The Cable Arm bucket was demonstrated by the Contaminated Sediment Removal Program (CSRP) on contaminated sediments in the Toronto and Hamilton Harbors in Canada in 1992 (Environment Canada 1993) and has been used for navigation maintenance dredging in the Cuyahoga and Fox Rivers.

Backhoes

Backhoes, although normally thought of as excavating rather than dredging equipment, can be used for removing contaminated sediments under certain circumstances. Backhoes are normally land based, but may be operated from a barge, and have been used infrequently for navigation dredging in deep-draft (20-ft [6-m]) channels. Backhoes have received limited use for removing PCB-contaminated sediments from the Sheboygan River. A backhoe was recently used to remove 13,000 m[3] of contaminated sediments from Starkweather Creek in Madison, Wisconsin. Sediment resuspension from the dredging was monitored and found to be no greater than that expected with other types of dredging equipment (Fitzpatrick 1994).

Specialized backhoes include closed-bucket versions and a pontoon-mounted model especially adapted to dredging applications (see WaterMaster described in St. Lawrence Centre 1993). The latter may be equipped with a suction pump as well.

Hydraulic Dredges

Hydraulic dredges remove and transport sediments in the form of a slurry. They are routinely used throughout the United States to move millions of cubic meters of sediment each year (Zappi and Hayes 1991). The hydraulic dredges used most commonly in the United States include the conventional cutterhead, dustpan, and bucket-wheel. Certain hydraulic dredges, such as the modified dustpan, clean-up, and matchbox dredges, have been specifically developed to reduce resuspension at the point of dredging.

Hydraulic dredges provide an economical means of removing large quantities of contaminated sediments. The capacity of the dredge is generally defined by the diameter of the dredge pump discharge. Size classifications are: small (4-14 in., 10-36 cm), medium (16-22 in., 41-56 cm), and large (24-36 in., 61-91 cm) (Averett et al., in prep.). The dredged material is usually pumped to a storage or disposal area through a pipeline, with a solids content of typically 10-20 percent by weight (Herbich and Brahme 1991). Souder et al. (1978) indicated that slurry concentrations are a function of the suction pipeline inlet velocity, the physical characteristics of the *in situ* sediment, and effective operational controls. The slurry uniformity is controlled by the cutterhead (if one is employed) and suction intake design and operation. The cutterhead (both conventional and innovative) should be designed to grind and direct the sediment to the suction intake with minimal hydraulic losses. Water jets can also be used to loosen the *in situ* material and provide a uniform slurry concentration. The dredgehead and intake suction pipeline should be designed to maintain velocities that are capable of breaking the *in situ* sediment into pieces that the pump can handle while minimizing entrance and friction losses.

The dredge pump and dredgehead (e.g., cutterhead) should work in tandem so that the entire volume of contaminated sediment comes into the system, while maintaining a slurry concentration that the dredge pump is capable of handling. The pump must impart enough energy to the slurry so that the velocities in the pipeline prevent the solids from settling out in the line prior to reaching the next transport mode or remediation process. A properly designed and operated dredgehead, suction intake and pipe, pump, and discharge pipeline system can minimize sediment resuspension while significantly reducing system maintenance and the likelihood of pump failure.

Fundamentally, there are four key components of a hydraulic dredge:

- The **dredgehead** is the part of the dredge that is actually submerged into the sediment
- The **dredgehead support** is usually a ladder as shown in Figure 4-1, but may instead be a simple cable or a sophisticated hydraulic arm
- The **hydraulic pump** provides suction at the dredgehead and propels the sediment slurry through a pipeline (It may be submerged or deck-mounted.)
- The **pipeline** carries the sediment slurry away from the dredgehead to the receiving area (e.g., CDF, lagoon)

Dredgeheads
Various types of dredgehead configurations are used to facilitate the initial loosening and gathering of bottom sediment. Most hydraulic dredges are usually identified by the type of dredgehead (e.g., bucket wheel dredge). Various types of dredgeheads are discussed below.

Cutterhead Dredges--Conventional cutterhead dredges are the most common hydraulic dredges in the United States. According to Averett et al. (in prep.), there are 300 such dredges operating in the United States today. A conventional open basket cutterhead is shown in Table 4-1.

Cutterhead dredges are usually operated by swinging the dredgehead in a zig-zag pattern of arcs across the bottom, which tends to leave windrows of material on the bottom (Herbich and Brahme 1991). Innovative operating techniques, including overlapping dredge or step cuts, can reduce or eliminate windrows. Cutterhead dredges can be operated to reduce resuspension or losses of volatile contaminants using additional equipment such as sediment shields, gas collection systems, underwater cameras, and bottom sensors.

Innovative dredgehead designs have been developed specifically for removing contaminated materials. Such dredgeheads put a premium on minimizing sediment resuspension and on accurate control of the depth of sediments removed. Two such dredgeheads, the Clean-up and the Refresher, are shown in Table 4-1.

Suction Dredges--This category includes those hydraulic dredges that do not employ a cutterhead. Such dredges may use water jets to help loosen sediments. Examples of three dredgehead designs used for such dredges are provided in Table 4-2.

Hybrid Dredges--These dredges use a combination of mechanical action and hydraulic pumping, but would not be considered cutterhead dredges. Examples of dredgehead designs used by hybrid dredges are shown in Table 4-3, and include the bucket wheel, screw impeller, and disc-bottom dredgeheads.

Dredgehead Support
The physical support for the dredgehead, or ladder, is largely interchangeable among the various dredges and will not be discussed further in this document.

Hydraulic Pumps
The three main applications of hydraulic pumps in the dredging process are:

- Dredge plant pumps used to remove *in situ* sediments
- Booster pumps used to maintain slurry velocities
- Pumpout stations used to rehandle sediment from hoppers, barges, and railcars

Dredge plant pumps are discussed in this section. The other two types of pump applications are discussed in Chapter 5, *Transport Technologies.*

Fundamentally, pumps are used to convert mechanical or pumping energy into slurry energy. Usually they are driven by electric or diesel motors, although air-driven (pneumatic) pumps have also become popular. Energy put into a slurry by a pump is used to maintain pipeline velocities while overcoming elevation heads and friction and entrance losses.

The two general classes of dredge plant pumps are kinetic and positive displacement (Lindeburg 1992). A summary of the characteristics of selected examples of these pump types is provided in Table 4-4 [part i] [part ii] [part iii].

Pipelines
Details on slurry pipelines are provided in Chapter 5, *Transport Technologies*.

Portable Hydraulic Dredges
Portable hydraulic dredges are relatively small machines that can be transported over land. They are convenient for isolated, hard-to-reach areas and are economical for small jobs. These dredges are also capable of operating in very shallow water (approximately 0.5 m). Two such dredges are the horizontal auger dredge and the Delta dredge (Delta Dredge and Pump Corp.). These two dredges are shown in Table 4-5. Two examples of horizontal auger dredges are the Mudcat, manufactured by Ellicott Machine Co. and the Little Monster, manufactured by the H & H Pump and Dredge Co. A Mudcat dredge with several equipment modifications was demonstrated by the CSRP in November 1991 at the Welland River, Ontario (Acres International Ltd. 1993).

A third type of portable dredge is the hand-held hydraulic dredge. This dredge can be as simple as a hose connected to a vacuum truck, such as the one used to remove PCB-contaminated sediments from the Shiawasee River in Michigan (USEPA 1985b). In another example, diaphragm sludge pumps were used by the USEPA's Inland Response Team to remove PCB-contaminated sediments from the Duwamish River Waterway in Seattle, Washington (Averett et al., in prep.). The primary application of such dredges is the removal of small volumes of contaminated materials that can be easily accessed from the surface or by divers.

Self-Propelled Hopper Dredges
A self-propelled hopper dredge operates hydraulically, but it is often described as a separate type of dredge because the dredged material is retained onboard rather than being discharged through a pipeline (Figure 4-1). Self-propelled hopper dredges are well suited for dredging large quantities of sediments in open areas. They are not well suited for small dredging projects, especially in close quarters. For these reasons, they are not likely to be used for sediment remediation projects around the Great Lakes and will not be discussed in further detail in this document.

Vessel or Dredgehead Positioning Systems

A critical element of sediment remediation is the precision of the dredge cut, both horizontally and vertically. Technological developments in surveying and positioning instruments have improved both aspects of dredging. Vertical control is particularly important where contamination occurs as a relatively thin or uneven layer. Video cameras can be used to continuously monitor dredging operations. The depth of the dredgehead can be measured using acoustic instrumentation and by monitoring dredged slurry densities. In addition, surveying software packages can be used to generate pre- and post-dredging bathymetric (water depth) charts, determine the volume dredged, locate obstacles, and calculate surface areas (St. Lawrence Centre 1993). A digital dredging method, which enables dredge operators to follow a complex sediment contour, has been developed in the Netherlands (van Oostrum 1992).

The horizontal position of the dredge may be continuously monitored during dredging. Satellite- or transmitter-based positioning systems (e.g., global positioning system, SATNAV, LORAN C) may be used to define the dredge position. In some cases, however, the accuracy of these systems is inadequate for precise dredging control. Very accurate control is possible through the use of optical (laser) surveying instruments set up at one or more locations onshore. These techniques, in conjunction with on-vessel instruments and control of spud placement, can enable the dredge operator to target specific sediment deposits.

The positioning technology described above may enhance the accuracy of dredging in some circumstances. However, planners and designers should not develop unrealistic expectations of dredging accuracy. Contaminated sediments cannot be removed with surgical accuracy even with the most sophisticated equipment. Equipment is not the only factor affecting the accuracy of a dredge. Site conditions (e.g., weather, currents), sediment conditions (e.g., bathymetry, physical character), and the skill of the dredge operator are all important factors. In addition, the distribution of sediment contaminants can, in many cases, only be resolved at a crude level and with a substantial margin for error. The level of accuracy required for environmental dredging should reflect the accuracy at which the sediment contamination distribution is resolved.

Containment Barriers

When dredging contaminated sediments, it may be advisable to limit the spread of contaminants by using physical barriers around the dredging operation. Such barriers may be appropriate when contaminant concentrations are high or site conditions dictate the need for minimal adverse impacts. A number of physical barriers commonly used in the construction industry may be adapted to this purpose. Structural barriers, such as cofferdams, are not generally applicable as temporary barriers, but are options for *in situ* containment (see Chapter 3, *Nonremoval Technologies*). The determination of whether these types of barriers are necessary, aside from regulatory requirements, should be made based on a thorough evaluation of the relative risks posed by the anticipated release of contaminants from the dredging operation, the predicted extent and duration of such releases, and the long-term benefits gained by the overall remediation project. The *ARCS Risk Assessment and Modeling Overview Document* (USEPA 1993a) and the *Estimating Contaminant Losses from Components of Remediation Alternatives for Contaminated Sediment* (Myers et al., in prep.) should be used to make this determination. More commonly, nonstructural barriers, such as oil booms, silt curtains, and silt screens, have been used to reduce the spread of contaminants during dredging. Oil booms are appropriate for sediments that are likely to release oils when disturbed. Such booms typically consist of a series of synthetic foam floats encased in fabric and connected with a cable or chains. Oil booms may be supplemented with oil absorbent materials (e.g., polypropylene mats).

Silt curtains and silt screens are flexible barriers that hang down from the water surface. Figure 4-3 shows a typical design of a silt curtain. Both systems use a series of floats on the surface, and a ballast chain or anchors along the bottom. Although the terms silt curtain and silt screen are frequently used interchangeably, there are fundamental differences. Silt curtains are made from impervious material such as coated nylon and primarily redirect flow around the dredging area rather than blocking the entire water column. In contrast, silt screens are made from synthetic geotextile fabrics, which allow water to flow through but retain a fraction of the suspended solids (Averett et al., in prep.).

Silt curtains have been used at many locations with varying degrees of success. For example, silt curtains were found to be ineffective during a demonstration in New Bedford Harbor, primarily as a result of tidal fluctuation and wind (Averett et al., in prep.). Similar problems were experienced when Dokai Bay (Japan) was dredged in 1972 (Kido et al. 1992). Barriers consisting of a silt curtain/silt screen combination were effectively applied during dredging of the Sheboygan River in 1990 and 1991. Water depths were generally 2 m or less. A silt curtain was found to reduce suspended solids from approximately 400 mg/L (inside) to 5 mg/L (outside) during rock fill and dredging activities in Halifax Harbor, Canada (MacKnight 1992). A silt curtain was employed during a dredging demonstration at Welland, Ontario (Acres International Ltd. 1993). The curtain minimized flow through the dredging area, although there were problems in the installation and removal.

Monitoring

Monitoring may be conducted during environmental dredging for a number of purposes, including:

- Measure contaminated sediment removal efficiency
- Determine dredged volumes
- Measure sediment resuspension at dredge
- Track contaminant transport
- Check performance of barriers and other controls

During maintenance dredging, monitoring is generally focused on the quantity of material dredged because the contractor is paid according to this quantity. The quantity of dredged material may be estimated from bathymetric surveys conducted before and after the dredging, or from other measurements, such as barge counts or pumping rates and duration.

Measurements of turbidity or suspended solids are made during sediment remediation and during some maintenance dredging operations to monitor the level of sediment resuspension caused by the dredge. Water samples are typically collected at one location upstream and several locations downstream from the dredging site. Additional water quality monitoring around the dredging site may be required by the State or other regulatory agencies. Monitoring programs for tracking contaminant transport and checking the efficiency of barriers and other controls are site-specific. During remedial dredging projects, sediment samples may be collected and analyzed after dredging to monitor the removal efficiency and to determine if additional passes by the dredge are needed.

SELECTION FACTORS

A number of publications on the selection of dredges for environmental applications have been published, including the *Guide to Selecting a Dredge for Minimizing Resuspension of Sediment* (Hayes 1986) and *Selecting and Operating Dredging Equipment: A Guide to Sound Environmental Practices* (St. Lawrence Centre 1993). Generally one of the key considerations in any dredging project involving contaminated sediments is the minimization of sediment resuspension. While this subsection focuses on the selection of dredging equipment, it should be noted that the operation of the dredge also has a profound effect on the rate of sediment resuspension (Hayes 1986). Selection of specialty dredges designed for minimal sediment resuspension does not guarantee superior results. The keys to an effective and environmentally safe dredging operation are:

- Selection of equipment compatible with the conditions at the site and the constraints of the project
- Use of highly skilled dredge operators
- Close monitoring and management of the dredging operation

Conventional dredging equipment, employed in a careful and efficient manner, can achieve results comparable to specialty dredging equipment.

Dredge Selection

The operational characteristics of selected dredges are summarized in Table 4-6. These characteristics may be used to help narrow the range of dredges potentially suited to a given remediation project. Other factors that can be used to guide the selection of an appropriate dredge for a site are discussed below.

Solids Concentration
There are two major factors that affect the desired solids concentration:

- **Compatibility with Other Components** In most cases, it is preferable to use a dredging system that is capable of delivering material at high solids concentrations. This tends to minimize the costs of handling, treating, and disposing of sediments. Mechanically dredged sediments do not require intensive dewatering, which is an expensive pretreatment process (see Chapter 6). Mechanical dredging keeps the volume of dredged material to a minimum and greatly reduces the costs of water treatment (see Chapter 9).

- **Distance to Treatment/Disposal Site** The feasibility of pipeline transport to the treatment/disposal site is discussed in Chapter 5, *Transport Technologies*. The ability to deploy pipelines, even temporarily, in highly urbanized areas can be limited. If access is unlimited, slurried sediments can be transported by pipeline several kilometers with the use of booster pumps. If pipeline transport is not feasible, sediments can be transported at high solids concentrations (e.g., as produced with mechanical or pneumatic dredges) by scows or barges.

Production Rate
For navigation dredging, the size of the dredge (and number of dredges) is largely dictated by the volume of sediments to be removed and the time allowed. The quantities of sediments dredged at remediation projects are small in comparison to navigation dredging, and factors other than sediment volume may influence the dredge size and production rates. Production rates may be deliberately reduced to minimize sediment resuspension or because of constraints caused by sediment transport, pretreatment, treatment, or disposal components.

Dredging Accuracy
Precise control of operational dredging depth is particularly important when dredged sediments are to be handled in expensive treatment and disposal facilities (Averett et al., in prep.). The vertical and lateral accuracy of the dredge is important to ensure that contaminated sediments are removed, while minimizing the amount of clean sediments removed. The accuracy of a dredging operation is only partially influenced by the type of dredge selected. Conditions of the site and sediments, the proficiency of the operator, and the rate of production all influence the accuracy of the dredge cut.

Dredging Depth
Dredges are limited to dredging areas with an adequate depth of water to accommodate the draft of the dredging vessel. This factor becomes important when contaminated sediments are located outside of navigable waterways. Some dredging equipment can be operated from land to access sediments in shallow waterways. The maximum depth to which dredges can reach is also limited. Some dredges are limited by the length of the dredging arm or ladder. Hydraulic dredging in very deep water (>20 m) may require submerged pumps or remotely operated dredges.

Ability to Handle Debris
Sediment, especially in urban areas, often contains large rocks, concrete, timber, tires, and other discarded materials. In cargo loading/unloading areas, pockets of coal, iron ore pellets, or other bulk materials may occur from spillage. Very large debris (e.g., greater than 0.5 m in any dimension) can only be removed mechanically (further discussion of specialized debris removal equipment is provided in Chapter 6). Mechanical dredges will generally remove large debris with the sediments, but are likely to produce greater turbidity in the process. Dredgeheads equipped with cutters are able to reduce the size of some debris such as wood. Although debris that is larger than the diameter of the suction pipe and not cut by the cutter simply cannot be removed by hydraulic dredges, smaller debris can also clog hydraulic pipelines and damage pumps.

Other Factors
In addition to the selection factors shown in Table 4-6, there are a number of other factors that may be significant in the selection of a dredge for a remediation project, including sediment resuspension, dredge availability, and site restrictions. These factors are discussed below.

Sediment Resuspension–In areas where sediments have high contaminant concentrations, toxicity, mobility, or a combination thereof, extraordinary care and expense may be required to minimize sediment resuspension or spillage. In such cases, releases of contaminants to the water are a primary concern, and may override other factors in selecting a dredge. As noted above, the degree of resuspension is influenced by both the type of dredge and its operation. Resuspension characteristics of dredges are discussed later in this chapter in regard to estimating contaminant losses.

Dredge Availability--A wide variety of dredging equipment is available throughout North America and in the Great Lakes region. A summary of dredges stationed in the Great Lakes is shown in Table 4-7. A summary of the availability of specialty dredges is provided in Table 4-8. As shown, many of the specialty dredges developed in Japan and Europe are not readily obtainable in the United States. The *International Dredging Review* publishes an annual directory of dredge owners and operators, which should be consulted for an up-to-date listing of dredging contractors and available equipment. ***Site Restrictions***--Channel widths, surface and submerged obstructions, overhead restrictions such as bridges, and other site access restrictions may also limit the type and size of equipment that can be used. For example, hopper dredges are ships that require navigable depths, cutterhead dredges require anchoring cables for operation, while bucket dredges can operate in confined areas. In some cases, it may be more appropriate to remove material from shore, as was done with contaminated sediments from Starkweather Creek in Madison, Wisconsin (Fitzpatrick 1994).

Containment Barriers

The effectiveness of nonstructural containment barriers at a sediment remediation site is primarily determined by the hydrodynamic conditions at the site. Conditions that will reduce the effectiveness of barriers include:

- Strong currents
- High winds
- Changing water levels
- Excessive wave height (including ship wakes)
- Drifting ice and debris

As a generalization, silt curtains and screens are most effective in relatively shallow, quiescent water. As water depth increases, and turbulence caused by currents and waves increases, it becomes increasingly difficult to effectively isolate the dredging operation from the ambient water. The St. Lawrence Centre (1993) advises against the use of silt curtains in water deeper than 6.5 m or in currents greater than 50 cm/sec.

The effectiveness of containment barriers is also influenced by the quantity and type of suspended solids, the mooring method, and the characteristics of the barrier (JBF Scientific Corp. 1978). Typical configurations for silt curtains and screens are shown in Figure 4-4. To be effective, barriers are deployed around the dredging operation and must remain in place until the operation is completed at that site. For large projects, it may be necessary to relocate the barriers as the dredge moves to new areas. Care must be taken that the barriers do not impede navigation traffic. Containment barriers may also be used to protect specific areas (e.g., valuable habitat, water intakes, or recreational areas) from suspended sediment contamination.

Monitoring

A monitoring program for environmental dredging should be designed to meet project-specific objectives. Monitoring can be used to evaluate the performance of the dredging contractor, equipment, and the barriers and environmental controls in use. Monitoring may also be integrated into the health and safety plan for the dredging operation to ensure that exposure threshold levels are not exceeded.

The monitoring program must be designed to provide information quickly so that appropriate changes to dredging operations or equipment can be made to correct any problems. Simple, direct, and preferably instantaneous measurements are most useful. Measurements of turbidity, conductivity, and dissolved oxygen can be used as real-time indicators of excessive sediment resuspension. Project-specific guidelines for interpreting monitoring results should be developed in advance, as well as potential operational or equipment modifications.

ESTIMATING COSTS

The basic principles of cost estimating, and the use of cost estimates to support the decision-making process are discussed in Chapter 2. More detailed guidance specific to estimating the costs of dredging operations is provided in this section. This guidance is applicable to feasibility studies, but is not adequate for preparing a detailed dredging cost estimate.

This document discusses the removal (Chapter 4) and transport (Chapter 5) components of a sediment remedial alternative separately. However, these components are likely to be part of a single contract, and their costs would, in most cases, be estimated together. Virtually all costs associated with the removal component of a sediment remediation project are capital costs (direct and indirect). The elements of environmental dredging costs include:

- Mobilization/demobilization
- Dredge operation

- Contaminant barriers
- Monitoring
- Health and safety
- Equipment decontamination

Each of these elements is discussed below, and available unit prices are presented. Although many of these unit prices are obtained from navigation dredging experience, only the operational costs are likely to be increased significantly during sediment remediation dredging as a result of the more slowed operation and decreased production.

Cost information is available from some historical sediment remediation projects. A total of 13,000 m[3] of sediments was excavated from Starkweather Creek in Wisconsin by backhoe at a cost of approximately $10.00/m[3] (Fitzpatrick 1994). The Waukegan Harbor Superfund project in Illinois removed 23,000 m[3] by dredging at a cost of $1.1 million (Albreck 1994). However, these and other unit dredging costs from historical remediation projects should only be used when all cost items are known.

Mobilization/Demobilization

The first cost incurred in any dredging project is that of bringing the dredging equipment to the dredging site and preparing it for operation. This process is referred to as mobilization. Demobilization occurs at the end of the project operation and typically costs one-half the mobilization expense. Typical mobilization/demobilization costs for the Great Lakes region (provided by USACE Detroit District) are as follows:

Cost (per 100 km)*

Mechanical dredge (clamshell) $37,500
Hopper dredge (<4,000 m[3]) $75,000
Hydraulic (pipeline) dredge $18,750

* Distance the dredge must be transported to the project site.

Mobilization costs for backhoes (without the requirement for a floating platform) are typically less than $400 (USEPA 1985a). Portable dredges are often leased or purchased outright.

Mobilization/demobilization may represent the largest single cost element in the dredging project, especially for projects with small dredging quantities. Additional costs will be incurred if specialized pumps or unconventional dredgeheads are employed. Generally, specialty dredging equipment may be transported separately to the site and used with the conventional dredging equipment. The costs for specialty dredging equipment must be developed on a site-specific basis.

Dredge Operation

The costs of a dredging operation depend on the size of the dredge employed and the amount of time that the equipment is onsite (i.e., the cost of dredging is largely a function of the production rate). In conventional dredging, the rate of production is fairly predictable, based on the consistency of the sediments and the size of the dredge employed. Algorithms for predicting the production rates of different dredge types are provided in Church (1981).

During environmental dredging, additional time must be allowed for other factors, such as:

- Greater precision of cut
- Slower production rates to minimize resuspension
- Multiple passes needed to achieve cleanup goals
- Use of contaminant barriers
- Restrictions posed by other remedial components

In most cases, additional costs will be incurred as the production rates are lowered.

One of the goals of environmental dredging is to remove only those sediments that are contaminated. Because of the costliness of treating or disposing of contaminated sediments, the quantity of clean sediments removed must be minimized. The production rate of the dredge may be deliberately slowed so that downstream components such as sediment handling and transport, pretreatment, treatment, disposal, and/or effluent treatment are not overwhelmed. This is particularly true for hydraulic (pipeline) dredging, in which adequate time must be allowed for sediments to settle out in the receiving basin (see Chapter 8). In fact, it may be more cost effective, in such instances, to select a smaller dredge that can be operated at a constant rate close to its capacity, rather than a large dredge with an operating schedule that is frequently interrupted.

Typical unit costs for various types of maintenance dredges are provided in Table 4-9. They reflect the costs of dredge operation for rates of production typical of maintenance dredging in the Great Lakes. These costs should be adjusted to account for the lower production rates anticipated with environmental dredging. The adjustment for environmental dredging production rates may be as much as 2 3 fold (or more) for specific applications. For example, the hydraulic dredging of 23,000 m[3] of sediments during the Waukegan Harbor Superfund cleanup cost $1.1 million, or roughly $48/m[3] (Albreck 1994). This cost included the deployment of a contaminant barrier (silt curtain).

Containment Barriers

Several types of containment barriers are available to contain contaminants released during dredging. Current unit costs for oil booms and silt curtains and screens are summarized in Table 4-10.

Monitoring

The costs of a monitoring program for an environmental dredging operation may be significant. However, these costs are project specific, and few generalizations can be made. Among the potentially more costly items of a monitoring program are detailed bathymetric surveys (before and after dredging), post-dredging sediment contaminant analysis, and sediment resuspension monitoring. The cost of sediment analysis will depend on the contaminants analyzed and the turnaround time requested of the laboratory. The primary costs for resuspension monitoring are for field sampling, as turbidity and suspended solids analyses are relatively inexpensive.

Health and Safety

The removal of contaminated materials from a waterway can be a hazardous activity, especially if contaminant concentrations are high. Depending on the types of contaminants present, the concentrations expected, and the degree of contact workers may have with the sediment, it may be necessary to provide workers with special PPE, such as respirators and Tyvek coveralls. Such gear can decrease the productivity of workers and thereby greatly increase operating costs. This is particularly true if workers are required to wear respirators or use supplied air. However, in most cases sediment contaminants are not volatile, and therefore respiratory protection is rarely needed.

Another health and safety consideration is the training of site workers. Workers at all Federal Superfund sites, as well as other hazardous waste sites, are required to undergo 40 hours of health and safety training (29 CFR 1910.120). This requirement may represent an additional expense not anticipated by the dredging contractor.

Equipment Decontamination

Reusable equipment that comes into contact with contaminated materials may have to be decontaminated prior to leaving the site. This is an expense not normally included with demobilization costs. The level of decontamination required will depend on the nature of the sediment contaminants and the laws and regulations governing the remediation. Large equipment such as dredges may have to be steam-cleaned or washed with detergents, unless it can be shown that contamination can be effectively removed using less intensive methods. It may be possible to clean pumps and pipelines by pumping clean water or clean sediment through them. All wash water from these operations would have to be captured and probably treated before being released.

ESTIMATING CONTAMINANT LOSSES

The loss of contaminants during dredging may need to be estimated for a number of reasons, including:

- Comparison and selection of dredging equipment
- Evaluation of the overall losses from remedial alternatives
- Determination of compliance with water quality requirements
- Determination of short-term impacts on sensitive resources

Factors that potentially affect contaminant losses from dredging are listed in Table 4-11.

A study conducted under the ARCS Program examined the available predictive tools for estimating contaminant losses from dredging (Myers et al., in prep.). The three mechanisms of contaminant loss from dredging are:

- Particulate contaminant releases
- Dissolved contaminant releases
- Volatile contaminant releases

Particulate Contaminant Releases

Methods for predicting sediment resuspension have been developed for cutterhead and mechanical (bucket) dredges. These methods predict the resuspension of particulates as a function of dredging equipment, operation, and sediment properties. These techniques have not been field verified, and are therefore not fully developed (Myers et al., in prep.).

Limited field studies have indicated that the type of dredging equipment used may have less effect on sediment resuspension than how it is used. The care with which a dredge operator excavates material has a significant effect on sediment resuspension (Hayes 1992). For example, variables such as cutter speed, swing speed, and degree of burial (bank factor) have been incorporated into models for cutterhead dredges (Myers et al., in prep.). Decreasing each of these parameters can reduce the resuspension caused by hydraulic dredging. Similarly, smooth and controlled hoisting can limit resuspension during clamshell dredging (McClellan et al. 1989).

Sediment properties are site-specific variables that cannot be controlled. In general, fine-grained, less-cohesive sediments have the greatest potential for resuspension and will travel further before resettling to the bottom.

The resuspension characteristics of numerous dredge types have been measured at various locations. A summary of resuspension tests is provided in Table 4-12, as compiled by Herbich and Brahme (1991), Zappi and Hayes (1991), and others. The comparability of sediment resuspension results from different sites is highly limited due to differences in the monitoring programs, sediment types, site conditions, and other factors. As indicated above, the type of dredge used is not always the most significant factor affecting sediment resuspension.

Dissolved Contaminant Releases

Resuspension of sediment solids during dredging can impact water quality through the release of contaminants in dissolved form. Dredging exposes sediments to major shifts in liquid/solids ratio and reduction/oxidation potential (redox). Initially upon resuspension, the bulk of the contaminants are sorbed to particulate matter. As the resuspended particles are diluted by the surrounding waters, sorbed contaminants may be released, increasing the fraction of dissolved contaminants in the water. Changes in redox potential (i.e., from an anaerobic to an aerobic environment) can affect metal speciation. This may increase the solubility of metals (e.g., oxidation of mercury sulfides) or decrease metal concentrations (e.g., metal scavenging by oxidized iron flocs) (Myers et al., in prep.). Organic contaminants are largely unaffected by redox shifts.

Methods for predicting the release of dissolved contaminants during dredging are less developed than those for sediment resuspension. A method using equilibrium partitioning concepts has been proposed for estimating the concentrations of dissolved organic contaminants, and a laboratory elutriate-type test has also been evaluated (Myers et al., in prep.).

Volatile Contaminant Releases

Dissolved organic chemicals are available at the air-water interface where volatilization can occur. Although the dissolved phase concentrations and therefore the evaporative flux are highest near the dredge, the mass release rate (flux times area) may be dominated by the lower concentration region away from the dredge.

Methods for predicting the rate of volatilization across the sediment-water interface are fairly well developed. To apply these methods at a dredging site requires the application of a mixing model to define both the area of the contaminant plume and the average dissolved-phase contaminant concentrations within that plume (Myers et al., in prep.).

Assessment and Remediation of Contaminated Sediments (ARCS) Program REMEDIATION GUIDANCE DOCUMENT

US Environmental Protection Agency. 1994. ARCS Remediation Guidance Document. EPA 905-B94-003. Chicago, Ill.: Great Lakes National Program Office.

5. TRANSPORT TECHNOLOGIES

Transport technologies are used to move sediments and treatment residues between components of a remedial alternative. In most cases, the first element of the transport component is to convey sediments dredged during the removal process to the disposal or rehandling site. Sediments may then be transported for pretreatment and then treatment, and treated residues may be transported to a disposal site. Transport is the component that links the other components of a remedial alternative, and may involve several different technologies or modes of transport.

Transport modes can include waterborne, overland, or a combination of these technologies. Waterborne transport modes include pipeline transport, hopper dredges, and barge systems. Overland transport modes include pipeline, railcar, truck trailer, and conveyor systems. In most cases, contaminated sediments are initially moved using a waterborne transport mode (pipeline or barge) during the removal process (one exception is when land-based dredging is used). Hydraulic removal technologies produce contaminated, dredged material slurries that are typically hauled by pipeline transport to either a disposal or rehandling site. Mechanical removal technologies typically produce dense, contaminated dredged material or excavated basin material for rehandling, which is hauled by barge, railcar, truck trailer, or conveyor systems.

Averett et al. (in prep.) provide a literature review of dredged material transport technologies. Other key resources for information on transport technologies include Churchward et al. (1981), Souder et al. (1978), Turner (1984), and USEPA (1979). Much of the information on transport technologies in the literature cited herein was developed for application to municipal sewage sludge, dredged material, and mining materials. The intended applications were generally scaled for very large quantities of materials. In many instances, these materials were transported over long distances, using permanently installed systems as part of long-term operations. In contrast, sediment remediation projects will typically move relatively small quantities of material over short distances and are often short-term operations. The feasibility and costs of transportation modes will be influenced by the scale of the remediation project.

This chapter provides a brief description of the pipeline, barge, railcar, truck trailer, and conveyor transport technologies. Discussions of the factors for selecting the appropriate transport technology and techniques for estimating costs and contaminant losses during transport are also provided. When transport modes are compared and contrasted with each other, the volumes of material being discussed are in-place cubic yards or cubic meters of sediment.

DESCRIPTIONS OF TECHNOLOGIES

Pipeline Transport

Temporary dredge pipelines are the most economically feasible mode for hauling contaminated dredged material slurries and water. For a sediment remedial alternative, pipelines may be used for the discharge from a hydraulic dredge; with the hydraulic pumpout from a tank barge, railcar, or truck trailer; and in routing process water, effluent, or leachate to treatment systems.

The amount of dredged material slurry generated during sediment removal is greatly affected by the contaminated sediment characteristics, removal equipment design, and removal equipment operation. Pipeline transport systems should be hydraulically designed and operated to minimize downtime while effectively moving this slurry. Equipment durability and pipeline routing greatly affect system downtime. Effective slurry transport consists of moving the slurry with minimal particle sedimentation in the line and with good line connections and minimal line wear and corrosion. Other factors being equal, fine-grained dredged material can be less costly to move (i.e., require less energy) than coarse-grained material (Denning 1980; Souder et al. 1978; USEPA 1979).

It is periodically necessary to halt dredging operations to add or remove sections of the pipeline to permit vessel passage or dredge advance, repair leaks, or reroute the line. Therefore, pipeline sections should be quick and easy to assemble, maintain, and dismantle. Although leaks can be welded, extra pipe sections should be readily available onsite to replace both land- and water-based pipeline sections that are clogged or leaking. Frequent monitoring helps to prevent excess leakage (Cullinane et al. 1986a).

Discharge Pipeline
Hydraulic dredge discharge pipelines can be identified by their properties (i.e., construction material, internal diameter, relative strength or schedule number, length, wall thickness, or pressure rating) or method of deployment (i.e., floating, submerged, or overland). Discharge pipelines typically range in length from <3 to >15 km (with boosters) (Cullinane et al. 1986a; Souder et al. 1978; Turner 1984). Souder et al. (1978) indicate that during commercial land reclamation projects slurries have been moved through pipelines of up to 24 km in length, and that a well-designed hydraulic dredge system can theoretically move some slurries >200 km using multiple booster pumps.

Discharge pipe sections are available in a variety of wall thicknesses and standard section lengths. The internal diameter, which is slightly larger than the diameter of the dredge suction line, ranges from 6 to 42 in. (15 to 105 cm; Turner 1984). Internal pipe section linings of cement, plastic, or glass can reduce the abrasion caused by slurry-entrained gravel, sand, and site debris; metal corrosion caused by sediment-bound contaminants and saline transport water; and the internal pipe roughness. In addition, internal abrasion and corrosion can be evenly distributed by periodically rotating each pipe section. External metal pipe corrosion can be controlled with coatings and/or cathodic protection.

Several types of discharge pipelines available for use are discussed below.

Rigid Pipeline–Rigid pipe sections can be constructed of steel, cast and ductile iron, thermoplastic, and fiberglass-reinforced plastic; the steel and iron sections are most commonly used. These sections can be joined by ball, sleeve, or flange joints to form discharge lines of varying lengths. The rigid nature of these sections permits longer, unsupported line spans and reduces the potential for damage while handling. Standard steel and iron pipe section lengths are 20, 30, and 40 ft (6.1, 9.1, and 12.1 m).

Flexible Pipeline--Flexible discharge pipe sections are constructed of either high-density polyethylene (HDPE) or rubber. The flexibility of the materials allows these sections to naturally adjust to wave action and shore contours. Therefore, these pipelines are easier to route than rigid pipelines. In addition, the flexible nature of these pipelines allows long-sweeping and more hydraulically efficient routing. However, flexible pipelines are far less commonly used than rigid pipelines.

Floating Pipeline–Discharge pipelines typically include a floating pipeline connected to the dredge pump(s) at the stern of the dredge hull. The floating pipeline can subsequently be run to a shore-based pipeline routed to the disposal or rehandling site. Because of concerns about obstructions in these pipelines and their overall stability, their use is typically limited to sections that connect the dredge pump to the land-based line. These sections provide for easy dredge movement (i.e., swing and advance). The dredge pump is connected to a floating rigid pipeline by either a rubber hose, swivel elbow, or ball joint(s). These lines are typically anchored at various locations.

Pipeline flotation is accomplished using pontoons or buoyant collars. Pontoons are typically constructed of metal cylinders with tapered ends, mounted to each end of a pipe section. The pontoons are joined together by rigid, wooden or steel beams. The rigid pipe section is attached to wooden pontoon saddles. Tender boats are used to move floating pipeline sections.

Obstruction of the waterway can be minimized by routing the pipeline to and along the shoreline. However, these pipelines should be placed in waters of adequate depth and distance from the shoreline to prevent the lines from dragging on the bottom and/or ramming the shoreline. When obstruction of the waterway is of little concern, the pipeline should be floated in a wide arc so that the dredge can advance without frequent stops to add additional pipe sections (Huston 1970).

Submerged Pipeline--Submerged pipelines can be used in place of floating pipelines in waterways where vessel traffic would require frequent dredge downtime to disconnect the line and permit passage. Submerged pipelines require two stationary points where the ends of the line can be fixed as they rise out of the water. For temporary lines, these points are typically well-moored barges (Huston 1970). Although less susceptible to damaging wave action, submerged pipelines should be used conservatively because inspection for plugs and leakage is difficult.

Shore Pipeline--Relative to floating and submerged pipelines, shore pipelines are made up of shorter (10-15 ft [3-5 m]) and generally lighter pipe sections. Pipe sections are joined and placed aboveground or on a cribbing. These lines should only be covered to protect the line from damage (i.e., traffic crossings, freezing/thaw conditions) because detection of leakage is difficult. Shore pipelines generally flow into a disposal or rehandling site.

Booster Pump

Booster pumps (kinetic or positive displacement) supplement the dredge pump(s) by increasing the distance a slurry can be pumped without particle sedimentation. Booster pumps are used when the output of the dredge pump(s) is so reduced by line routing that the cost of a booster pump is justified by the increased productivity it achieves. Although easier to design, booster pumps do not have to be identical to the dredge pump(s). For dredges that operate with long discharge lines and require booster pumps, Turner (1984) indicated that installing a booster pump on the dredge hull would reduce labor and maintenance costs. This layout would lower the labor costs typical of line booster pumps but would increase material costs for pipelines necessary to withstand increased pressures.

Booster pumps are installed to form a series of identical pumping stations (barge- or land-based) generally spaced uniformly from the dredge to the disposal or rehandling site. At each pumping station, two essentially similar pumps are arranged in series. However, if deemed necessary to optimize the reliability of the operation, an auxiliary spare pump and motor with all pertinent piping, valves, and connections can be provided for emergency use in the event of a major breakdown in the primary equipment. Positive displacement booster pumps used in combination with a centrifugal dredge pump would require a booster pump holding facility because it is practically impossible to match positive displacement pumping rates to centrifugal pumping rates (USEPA 1979).

Barge Transport

Transport barges or scows can be defined as cargo-carrying craft that are towed or pushed by a powered vessel on both inland and ocean waters (McGraw-Hill 1984). Barge transport is the most common means of transport for mechanically dredged material. Features of barge transport that are discussed in this section are barge types, tow operations, and loading/unloading operations.

Barge Types

Three types of barges that are applicable to sediment remediation projects are the tank, hopper, and deck barges. The features of these barges are provided in Table 5-1. Tank barges are most frequently used to haul coal, petroleum and petroleum products, agricultural products, iron, steel, and chemicals. Sectionalized compartments provide structural stability to the barge hull, distribute cargo loads more evenly, help prevent cargo from shifting while in tow, and allow each section to carry different types of cargo.

Hopper barges are designed specifically to deliver bulk material to open-water disposal sites, and are the most commonly used barges for transporting dredged material. Early hopper barge designs used mechanically driven chain, cable, sheave, and releases to open the cargo compartment door(s). Recent designs use high-pressure hydraulic systems. Split-hull and continuous compartment bottom and side-dump hopper barges are simultaneously dumped, whereas bottom and side-dump hopper barge sections can be dumped individually.

The Buffalo District studied the leakage from hopper barges and concluded that all hopper barges leak to some degree. They concluded that all hull seams should be carefully shut and stabilized with sandbags, hay bales, and/or plastic liners to help minimize hull leakage.

Deck barges are simply a flat work surface and may be used as a work barge (i.e., anchor, derrick, jack-up, mooring, office, pontoon, quarterboat, service, shop, store, or survey barges) or the platform for the dredge. During a sediment remediation project on the Black River in Lorain, Ohio, a single deck barge was used as the platform for a bucket dredge and several dumpsters that were used to contain the dredged sediments. After the dumpsters were filled, the barge was brought to the shore, where the dumpsters were offloaded to flatbed trucks and hauled to a nearby disposal site.

Barge hulls can be of either single- or double-walled construction. The bow and/or stern of a barge hull is either vertical (box-shaped) or raked (angled). Raked hulls provide less tow resistance, thereby resulting in fuel savings, while box-shaped hulls are typically limited to barges on the interior of an integrated tow of multiple barges. Barges operated in moderately high wave areas can be constructed with a notched stern in which the towboat bow fits. This connection provides greater resistance to longitudinal movement along the vessel interface and enhances control under adverse conditions (Churchward et al. 1981).

Tow Operations
In the absence of significant wave action, the best position for a towboat is at the barge stern (Churchward et al. 1981). While the main factor in selecting a towboat is its ability to maneuver and push or tow the barges, the towboat's draft is also an important factor. The towboat draft should be consistent with site and transport route water depths to prevent sediment resuspension from propwash and hull dragging. Towboats are also used to move the dredge floating plant (when not self-propelled).

Although grain- or coal-filled barges are typically moved in large, integrated tows (up to 40 barges), dredged material-filled barges are generally hauled individually. A typical maintenance dredging operation might use two barges (one is filled by the dredge while the other is being transported to or from the disposal or rehandling site). If the distance between the dredging and disposal or rehandling site is long, additional barges and towboats may be used. The objective is to have sufficient barges and towboats available to keep the dredge operating continuously.

Spillage during transport can result from overfilling the barge or from a leaky hull. Risks of spillage are especially great when moving through rough waters. Overfilling can be prevented by filling the barge only to the bottom of the barge coaming. Spillage while in tow can be prevented by placing removable covers over the barge coaming. Barge hulls should be inspected regularly to ensure that they are completely sealed.

Loading/Unloading Operations
Tank and hopper barges are typically loaded by first pulling the barge adjacent to the dredge floating plant. Dredged sediment is frequently splashed or dropped onto the deck of a barge during loading operations. Spillage can be reduced by minimizing the height from which the bucket releases its load. Dredge operators should place the bucket into the cargo compartment before releasing the load and not drop it with any freefall. In addition, tank barges should be loaded uniformly to prevent excessive tilting or overturning.

During maintenance dredging of uncontaminated sediments, supernatant is allowed to overflow during filling to increase the barge's payload (i.e., reduce the amount of water hauled). Because of the potential for contaminant release and the inefficiency of barge overflow for fine-grained sediment, supernatant overflow should not be permitted on contaminated sediment dredging projects. Methods to remove free-standing water from barges, including the use of polymer flocculants, have been investigated by some Corps districts to produce more economical loads with contaminated dredged material (Palermo and Randall 1990).

Most barges can be unloaded using a variety of mechanical equipment, including cable, hydraulic, or electrohydraulic rehandling buckets (Hawco 1993). Backhoes and belt conveyors or bucket line dredges can also be used to unload barges. All unloading facilities should be equipped with drip pans or aprons to collect material spilled while unloading the barge and loading the material onto a railcar, truck trailer, or conveyor or directly into a disposal or rehandling facility.

Mechanically dredged sediments have been unloaded from barges to CDFs using a modified hydraulic dredge or submerged dredge pump. Water from the rehandling site or disposal facility (where available) is added to the barge and mixed in with the sediment to provide a uniform slurry for the rehandling dredge pump.

Railcar Transport

Railcar transport is widely used in the transport of sewage sludge, but has not been used for the transport of dredged material (according to available literature). However, railcar transport of contaminated sediments may be feasible when travel distances are especially long (i.e., >160 km).

Railcar designs can include tank, hopper, deck, and box cars (Churchward et al. 1981). Mechanically filled tank and hopper railcars are most likely the only economical means of hauling contaminated dredged material. The features of tank and hopper railcars are summarized in Table 5-2. Tank cars might also be used to haul liquid treatment residues. Souder et al. (1978) indicate that railcars of the 70- to 100-net ton class are preferable for hauling bulk materials such as dredged sediment. Tank and hopper railcars can be constructed with permanent or hatched covers to prevent weather effects and spilling or leaking of material or water from the car. Like barges, railcars should be uniformly loaded.

Railcars are pulled by either diesel- or electric-powered locomotives. However, with the exception of switching facilities, railcars must be hauled by a railroad company locomotive, requiring a contract that can take several months to obtain (USEPA 1979). Larger trains (railcar capacity and number of cars) are limited by track system designs and crossing times.

Tank Railcars
Rectangular tank railcars are typically used to haul dense materials. They are unloaded by moving them off the mainline track to an elevated loop track, disassembling the train, and dumping each car using rotary car unloading equipment. The rotary car technique turns the railcar upside down to allow gravity drainage. Swivel tank car connections can be used to avoid disassembling the train during rotary dumping. Rotary dumping equipment is very expensive and generally works best for non-cohesive materials (Souder et al. 1978). Shaker units can be used to help unload the typically cohesive contaminated dredged material.

Cylindrical railcars are typically used for hauling liquid cargo and could be used for hauling dredged material slurries. These cars are hydraulically filled and are unloaded by moving them to an elevated track to allow gravity drainage through a hatch or valve opening(s) on the car body. Tank cars can also be pumped out.

Hopper Railcars
Similar to tank railcars, hopper railcars are typically unloaded by moving them to an elevated loop track. Hopper railcars are unloaded by opening the bottom-mounted hopper door(s) or hatch(es) to allow gravity drainage (Souder et al. 1978). Unlike rotary unloading, bottom dumping of hopper railcars does not require disassembly from the train prior to unloading and, depending on the material cohesion, the train may not even have to come to a complete stop.

Truck Trailer Transport

Truck trailer transport is the most common mode of transportation for hauling mechanically dredged material to upland disposal sites. Truck cargo compartments can include van (open and closed tops), flat, tank (liquid or pneumatic cargo), dump, depression deck, rack, or refrigerated (van or tank) types (Churchward et al. 1981). However, only tank and dump compartments are suitable for hauling dredged material and liquid treatment residues. The features of these types of trailers are summarized in Table 5-3.

Tank and dump compartments can be mounted on a single diesel- or gas-powered tractor chassis or mounted on a trailer chassis and towed by a tractor over both paved and unpaved roads. To minimize the number of drivers required and to allow loading to continue while other trucks are en route, it is desirable to use excess trailers. As with barge and railcar transport, mechanically filled trailers are the only economical means of hauling contaminated dredged material by truck. Liquid treatment residues (e.g., contaminated oil residue from solvent or thermal extraction processes) can be hauled in cylindrical tank trailers.

Trailer gates and hatches can be sealed with rubber gaskets, straw, or other materials to prevent leakage or spillage. During a dredging operation at Michigan City, Indiana, the bottom of dump truck flap gates were lined with sand, and a street sweeper was used to clean any drippage on public roads. Dump truck gates fitted with neoprene seals and double redundant locking latch mechanisms were used to haul dredged material during the Starkweather Creek cleanup in 1992 (Fitzpatrick 1993). Like barges and railcars, trailer covers can be installed to minimize odor releases during transport, to prevent spillage from sudden stops or accidents, and to prevent weather damage. Trailers should also be uniformly loaded.

Conveyor Transport

Conveyor systems have been widely used for the transport of sewage sludge and for material transport in mining and mineral processing (USEPA 1979). Within a sediment remedial alternative, conveyors might be used to transport mechanically dredged sediments from barges to disposal or rehandling sites, from rehandling sites to pretreatment and/or treatment systems, between process units of a pretreatment/treatment system, and, for solid residues, from treatment systems to disposal sites or to other transport modes.

Conveyor transport systems include belt, screw, tabular, and chute systems. The features of the belt and screw conveyor systems are summarized in Table 5-4. These conveyor systems typically require a loading or feeder bin from which the material is placed on the conveyor. An unloading or feedout bin may also be required, depending on whether the material is going to a disposal/rehandling site, a pretreatment or treatment unit, or another mode of transport.

Commercially available conveyor systems can be permanently installed or portable. Portable conveyors provide system flexibility and allow material to be placed over a wider area. These systems are most practical for handling small volumes of mechanically dredged material (USEPA 1979; Souder et al. 1978). For example, a small conveyor system was used to transport materials in the pilot-scale demonstration of sediment washing technologies conducted for the ARCS Program at Saginaw Bay, Michigan (USACE Detroit District, in prep.).

Conveyors have low operating costs and move high volumes with minimal noise and air pollution. However, they can be expensive to purchase and very labor intensive and, like pipelines, may require right-of-way permission. Chute systems that lead from one flight to another can become clogged by oversized pieces. Like pumps and pipelines, conveyors are a continuous system; therefore, if one segment fails the whole system fails (Souder et al. 1978).

Chute or inclined plane conveyors or slides have no mechanical parts. Chutes have been used to move mechanically dredged sediments from barges into CDFs adjacent to navigable waterways. Examples of chutes used at the Chicago Area CDF are shown in Figure 5-1. Sediments were unloaded from the barges using a crane and small bucket and placed onto the chute, which carried the sediments into the CDF. In some cases, water was sprayed onto the chute to help move the material. Based on the use of chutes for sewage sludge, it is recommended that the incline be greater than 60deg. for dewatered material and greater than the material's natural angle of repose for dried material. These systems can be open or covered to prevent spillage (USEPA 1979). Relatively shallow slopes (30deg. and less) have been used with slides transporting wet dredged material.

SELECTION FACTORS

The limitations of each transport technology should be considered prior to selecting the contaminated sediment transport mode(s). These limitations might include legal, political, sociological, environmental, physical, technical, and economic practicality. Souder et al. (1978) developed a generalized sequence for selecting alternatives for inland transport of clean dredged material. The selection factors for contaminated sediment transport adapted from Souder et al. (1978) include: compatibility with other remedial components, equipment and route availability, compatibility with environmental objectives, and costs.

Compatibility with Other Remedial Components

The selection of transport modes should be among the last decisions in the planning of a sediment remedial alternative. In many cases, the selection of other remedial components will eliminate all but one or two transport modes for consideration. For example, a remedial alternative involving hydraulic dredging will, with few exceptions, necessitate pipeline transport. Mechanically dredged sediments, on the other hand, can be transported using any of the modes discussed, including pipeline transport (although sediments will have to be slurried).

Some disposal/rehandling facilities can accommodate both hydraulically or mechanically transported sediments. Others, because of limited size or design features, cannot accommodate loadings by hydraulic slurry. Many treatment and pretreatment technologies have rigid restrictions on both the character and rate of feed material delivery. Residues from pretreatment or treatment systems may require continuous handling to subsequent components, or may be stockpiled for bulk handling. Transport modes must therefore be compatible with all components of a remedial alternative.

Equipment and Route Availability

Equipment Availability
Availability is rarely a limiting factor in the selection of transportation equipment. Most contaminated sediment sites are in urban areas, with transportation equipment available from several sources. At worst, equipment will have to be brought in from a greater distance, increasing the mobilization and demobilization costs.

> ***Pipeline and Barge Transport***--Equipment for waterborne transport is readily available for leasing from dredging and marine construction contractors. The availability of specific equipment, including pipelines and barges, will reflect regional markets for their use and the dimensional restrictions (e.g., vertical clearance, width, draft) of regional waterways. Dredging/marine construction trade journals, such as *International Dredging Review*, *Terra et Aqua*, *World Dredging, Mining and Construction*, and *The Waterways Journal*, contain the names of contractors and advertisements for equipment lease or purchase.
>
> ***Railcar Transport***--Railcars filled with sediments or treatment residues may be added to an existing train route or transported as an entire trainload of railcars or "unit train." Single-car transport can require that a railcar be switched from train to train several times, resulting in increased costs. A unit train operation, commonly applied to hauling coal, is negotiated with a railroad company and is dedicated to carrying only one commodity from one point to another on a tightly regulated and continuing schedule.
>
> A unit train operation could haul from 70 to 140, 100-ton (91 tonne) railcars (approximately 10,000 tonnes of contaminated dredged material) over distances of 80-2,400 km. Souder et al. (1978) recommended haul volumes of greater than 380,000 m [3] and haul distances greater than 80 km to support a unit train operation. A shorter haul distance increases the cost significance of loading and unloading.

Trailer Transport–A variety of truck trailer rigs may be leased or contracted through most large construction companies. There are numerous State and Federal restrictions on the size (vehicle width, height, and length) and weight of truck trailer rigs. Some regulations limit the number of trailers in tow by a tractor. Some weight regulations provide for the maximum weight that can be carried on single and multiple tandem (two grouped) axle groupings. However, most weight restrictions relate the overall or gross weight to the vehicle's wheel base. Most State regulations limit truck trailer loads to about 25 tons (23 tonnes). Other regulations include speed limits; requirements for safety features such as speedometers, brakes, horns, lights, windshield wipers, mirrors, and bumpers; and requirements for liability insurance. Some local ordinances even restrict truck operations to certain hours of the day and to certain routes (Souder et al. 1978).

Conveyor Transport--Conveyor systems are widely used in wastewater treatment and mining applications. Conveyor equipment may be purchased from suppliers to these industries identified in trade journals, including *Water and Waste Digest* and *Waterworld Review*. Some types of conveyor equipment may also be available for lease from the manufacturers or from dredging and construction contractors. Chutes and slides are typically fabricated by the dredging/transport contractor from purchased or available material. One dredging contractor split two abandoned railroad tank cars in half lengthwise and welded them into an open slide for transporting dredged material into the Chicago Area CDF (Figure 5-1).

Route Availability

Factors associated with transport routing include route constraints and scheduling. Route constraints include the availability of existing routes, rights-of-way for access, size and weight limits, and site obstructions. Transportation routes should run through areas that would be the least sensitive to accidental releases, where possible. The entire route should be easily accessible for maintenance, monitoring, and spill response. Site obstructions can affect the transport modes, or the transport modes can block traffic flow on existing routes. Scheduling difficulties may result from traffic interruption, overloads, and shutdowns due to harsh weather conditions (Souder et al. 1978). Routing difficulties can result in lengthy transport times, decreased efficiency, and increased costs.

Pipeline Transport--To deploy pipelines for a sediment remediation project, easements and rights-of-way must be obtained for the entire route. The ability to obtain even temporary easements for pipelines will be complicated because of the contaminated nature of the sediments. Pipeline crossings at roads and railroads may require special construction or excavation. Because sediment remediation projects are most likely in highly urbanized/industrialized areas, routing may be a major limitation in the use of pipelines.

Barge Transport–Barge selection, routing, and transit time are greatly affected by channel dimensions, site obstructions, other channel and seasonal conditions, speed limits and other restrictions, traffic congestion, and user fees. In addition to the length, width, and depth of a channel, other factors affecting barge access include lock sizes, bend radii, and structures (e.g., piers, jetties). Barge and tow boat drafts (loaded) should be less than the shallowest channel depth in the dredging area and on the tow route. Site obstructions can include height limitations caused by bridges or power lines and submerged objects such as cables, pipelines, piles, and rock. Transient or seasonal conditions that can affect barge access include water depths, currents, tidal influence, wave action, and icing. The number of barges required for a project will depend on the dredge production rate, haul volume, and travel time (distance, routing, unloading).

The majority of barge traffic in the Great Lakes area is limited to relatively short hauls that run close to lake shorelines. However, barge dimensions allowed in the Great Lakes area are typically larger than those of other inland barges because of larger lock dimensions (Churchward et al. 1981). The potential for substantial wave action generally demands that ocean-going barges (self-propelled or towed) or ships traverse the Great Lakes.

The *U.S. Coast Pilot* (a National Ocean Service annual report) contains detailed information about navigation regulations and channel restrictions for the Great Lakes and connecting channels. Navigation charts are available from NOAA. Additional information about channel restrictions, traffic, and user fees can be obtained from local harbor authorities, the Corps, or the U.S. Coast Guard.

Railcar Transport--With the exception of short spurs constructed to provide access to a disposal site, economic railcar transport typically demands the use of existing railroad track lines. These track lines are readily available in most industrialized areas. Mainline spur construction, if permitted, would be too expensive for low-volume dredged material transport. In addition, efficient railcar loading and unloading (bottom or rotary dump) facilities are required to make the unit train concept work and to realize the benefits derived from reduced rates on a large haul.

Truck Trailer Transport--There are about 5.6 million km of paved roads in the United States, of which about 912,000 km (25,600 km of interstate) can be considered for a transport system route (Souder et al. 1978). However, unpaved roads can be constructed relatively quickly at nearly any project site. Therefore, truck routes are more flexible and faster to construct than either waterway or railroad track routes. Because terminal points and routes can be changed readily at little cost, truck trailer transport provides a flexibility not found with other modes of transportation.

Compatibility with Environmental Objectives

Transport technologies are inherently designed to contain their cargo during transport. With the exception of volatilization, contaminant losses (e.g., leakage during transport or spillage during loading or unloading) are generally the result of poorly maintained or operated equipment. Most transport modes have one or more controls that can be applied to limit leakage occurring as a result of transport and spills during loading and unloading (e.g., covers, gate seals, splash aprons); however, these controls are only a few of the necessary steps to minimize contaminant losses. Transport equipment should be tested for leaks prior to hauling contaminated material and should be carefully monitored during operation. As with dredging operations, the amount of spillage during rehandling is greatly affected by the time and care taken by equipment operators.

The exteriors of barges, railcars, and truck trailers should be cleaned prior to leaving the loading or unloading facilities. These loading/unloading areas should be designed so that cleaning and runoff water can be collected at a central location and treated as necessary. After final use, barge, railcar, truck trailer, and conveyor interiors can be decontaminated using high-pressure water sprays. Pump/pipeline systems can be decontaminated by pumping several pipeline volumes of clean water through the system.

The applicability of Federal, State, and local environmental laws and regulations on the transport of contaminated sediments and treatment residues should be investigated on a case-specific basis. Federal regulations on the transport of hazardous and toxic materials include the Hazardous Materials Transportation Uniform Safety Act, RCRA, and TSCA. Specific requirements exist for transport, including registration, labeling, packaging, placarding, and material handling (UAB 1993).

Waterborne transport of contaminated materials may also be regulated by the International Maritime Dangerous Goods Code, which identifies some materials as "marine pollutants" with specific stowing requirements (Currie 1991). Federal regulations generally address interstate transport, and State and local regulations covering intrastate transport may differ from the Federal regulations (UAB 1993).

Virtually all transport modes have environmental effects unrelated to their cargo. Towboats, trucks, trains, and conveyors all have exhaust from their diesel- or gas-powered engines or generators. Towboats used to transport barges may cause sediment resuspension along the route, especially at locations where the barge accelerates, decelerates, or changes directions. A number of studies have been conducted to evaluate the physical, biological, and chemical effects of commercial navigation traffic in large waterways (Miller et al. 1987, 1990; Way et al. 1990; Miller and Payne 1992, 1993a,b).

ESTIMATING COSTS

The transport component of a sediment remedial alternative may incorporate several modes of transport to connect different components. For example, the remedial alternative shown schematically in Figure 5-2 uses pipeline transport between the hydraulic dredge and the rehandling facility. Dewatered sediments are removed from the rehandling facility using a front-end loader and placed onto a conveyor for transport to a pretreatment unit (rotary trommel screen). The primary residue of the pretreatment unit is transported to the thermal desorption treatment unit by another conveyor. The oversized residues of the pretreatment unit and the solids residues of the treatment unit are transported to the disposal facility by conveyor. The liquid (organic) residue of the treatment process is placed into a tank trailer for transport to a commercial incinerator. Water from the rehandling, pretreatment, treatment, and disposal units is routed to a wastewater treatment system through pipelines.

For a remedial alternative such as the one shown in Figure 5-2, it is likely that some modes of transport would be subcontracted as parts of other components (e.g., the pipeline would be supplied by the hydraulic dredging contractor), while others (e.g., conveyors) might be subcontracted separately. For most sediment remediation projects, all transport equipment would be leased or contracted. The transport costs would therefore be entirely capital costs, with no operation and maintenance costs.

Churchward et al. (1981) indicate that the main considerations for selection of the transport modes include cost, flexibility, capacity, and speed. A comparative analysis of these characteristics for pump, barge, railcar, and truck trailer transport, as developed by Churchward et al. (1981), is shown in Table 5-5.

In comparison with the other components, especially treatment, transport unit costs are relatively low. Therefore, the transport process should be scheduled for continuous operation to ensure that the other, more expensive processes can operate without interruption.

Souder et al. (1978) indicate that cost estimates should be regarded as generalized evaluations of the related costs of selected transportation modes under representative operating conditions. When specific applications are considered, the unique aspects of each application (e.g., terrain, weather conditions, labor rates) should be evaluated individually and more precise costs related to each specific application should be derived. The Corps' *Construction Equipment Ownership and Operating Expense Schedule* (USACE 1988) contains a method for computing dredging plant operating rates, which includes methods for estimating pipeline and barge transport costs.

Dredged material transport involves three major operations: loading, transport, and unloading. The loading and unloading activities are situation-dependent and are the major cost items for short-distance transport.

Souder et al. (1978) evaluated the costs of transporting large volumes (300,000 to >2.3 million m[3]) of clean dredged material over long distances (up to 500 km) as part of a study conducted by the Dredged Material Research Program. They indicate that, irrespective of the volume of material to be transported, the truck trailer and conveyor transport modes were considerably more expensive than the pipeline, barge, or railcar transport modes. They further concluded that truck trailer transport is labor- and fuel-intensive in comparison to other transport systems. Conveyors have a high investment cost but can move material efficiently. At lower volumes, conveyor costs are much higher than for other systems. However, at high volumes and shorter haul distances (<30 km) conveyor costs are competitive with all other transport modes except the pipeline system (not including conveyor chute systems for unloading facilities).

Based on technical considerations and cost derivation assumptions, Souder et al. (1978) concluded that pipeline transport is the most economical choice in most instances for transport volumes up to 760,000 m[3] and distances up to 160 km. Depending on the transport volume, barge or railcar transport will be the most economical systems for long-distance hauls. Railcar transport becomes more economical at higher volumes. Because of routing limitations, not all haul distances will be the same for each transport system.

Souder et al. (1978) indicated that for haul volumes <380,000 m[3] it is very difficult to realize the economies of scale required to achieve the relatively low transport rates derived in their analysis. If the transport costs developed by Souder et al. (1978) were modified for application to sediment remediation projects, it is likely that the loading/unloading costs for barge, truck trailer, and rail transport would increase because of the controls required to limit spills, and the relative costs of conveyors might be more favorable for the short hauling distances, such as those between remediation components (i.e., <1.5 km).

Pipeline Transport

For projects involving hydraulic dredging and pipeline transport over short distances (<3 km), the costs for pipeline equipment, mobilization, and labor are included in the dredging costs, as described in Chapter 4. Separate transport costs should be developed for pipeline transport over longer distances, or for pipeline transport of sediment or residues independent of the dredging contract.

Souder et al. (1978) developed unit cost information for pipeline transport of various dredged material haul volumes from a rehandling basin to a disposal site at various haul distances. This hypothetical operation involved using a portable dredge to remove the dredged material from the rehandling basin and transporting the material by a permanently installed pipeline, operated by a contractor. However, the unit cost information provided here was adjusted to include only the discharge pipeline, centrifugal booster pump, and related labor costs. No real estate or right-of-way costs were considered.

Unit cost estimates for this hypothetical operation are shown in Figure 5-3. These unit costs include the discharge pipeline and booster pump costs, including installation, maintenance and repair, lay-up time, insurance, and miscellaneous costs. Discharge pipeline costs include annual costs for the purchase of the pipeline. Centrifugal booster pump costs include annual costs for the pump and motor, reduction gears, controls, foundation, and housing, and costs for power and a sealing water supply (Souder et al. 1978).

Barge Transport

Barge carriers include major-line, branch-line, and local operations. Barge transport on the Great Lakes is provided under contract rates or long-term charters, with 26 percent of services provided by independent carriers (Churchward et al. 1981). Many dredging firms own barges and will subcontract additional barges as needed for a large job. For a project involving mechanical dredging and barge transport over short distances (i.e., <5 km), the costs for barge transport are included in the dredging costs presented in Chapter 4. If longer haul distances are required, or for barge transport of sediments or residues independent of the dredging contract, additional transport costs need to be estimated.

Souder et al. (1978) developed unit cost information for contracted tank barge transport of various dredged material haul volumes from a rehandling basin to a disposal site at various haul distances. This hypothetical operation involved using a bulldozer and backhoe to excavate the rehandling basin material, placing the material in a dump truck, moving the material from the truck into the tank barge, towing the barge to the disposal site, removing the material from the barge using a rehandling bucket, placing the material into a dump truck, and dumping the material into the disposal site.

Unit cost estimates for this hypothetical operation are shown in Figure 5-4. The cost information assumes that the rehandling basin and disposal site are both 2.4 km, by way of an existing road, from an existing barge mooring dock. As with the pipeline transport operation, this operation assumes that dredged material is transported under ideal conditions. Project-specific conditions may greatly affect these costs. The operation costs include annual costs for barge loading and unloading and the towboat and barge. Loading costs include backhoe, bulldozer, dump truck, and road maintenance costs. Unloading costs include crane and dump truck costs. Transport costs include towboat and barge costs, crew quarters and subsistence pay, and miscellaneous costs.

The cost engineering office of the Detroit District typically uses unit costs in the range of \$0.70 to \$1.50/yd[3]-mile (\$0.57 to \$1.23/m[3]-km) for preliminary estimates of barge transport of dredged material in the Great Lakes (Wong 1993).

Railcar Transport

Railcar rates are quoted by either a class rate or commodity rate. Class rates generally apply to small-volume shipments like single-car transport and occur on an irregular basis. These rates are influenced by route terrain and distance, the number of railcar switches required, and the haul volume. Class rates are readily obtained, but are usually prohibitively expensive for hauling dredged material. Commodity rates generally apply to regularly scheduled shipments of large volumes, like unit train transport, and are obtained from local rail carriers on a case-by-case basis. Commodity rates are lower than class rates (USEPA 1979; Souder et al. 1978).

Souder et al. (1978) developed unit cost information for contracted hopper railcar transport of various dredged material haul volumes from a rehandling basin to a disposal site at various haul distances. This hypothetical operation involved excavating the rehandling basin material using a backhoe and placing it on a conveyor system that emptied into a hopper railcar. The railcars were towed by a locomotive to the elevated loop track at the disposal site where the material was emptied.

Unit cost estimates for this hypothetical operation are shown in Figure 5-5. The operation costs include annual costs for hopper railcar loading and unloading and the locomotive and railcars. Loading costs include a backhoe, portable and fixed conveyor systems (including feed and feedout bins), and elevated loop track construction costs. Unloading costs include elevated loop track construction costs. Transport costs include locomotive and railcar carrier costs.

Tank railcars are usually leased by the month from a private tank car rental company, with a 5-year minimum lease. In 1978, a large tank car rented for \$450/month (USEPA 1979). Hopper railcars are usually leased from the carrier.

Truck Trailer Transport

Souder et al. (1978) developed unit cost information for contracted dump trailer transport of various dredged material haul volumes from a rehandling basin to a disposal site at various haul distances. This hypothetical operation involved using a backhoe to excavate the rehandling basin material and placing the material on a conveyor system that emptied into the dump trailer. The filled trailer was towed on an existing roadway to a newly constructed road leading into the disposal site and emptied.

Unit cost estimates for this hypothetical operation are provided in Figure 5-6. The operation costs include annual costs for loading the dump trailer and transporting it to the disposal site. Similar to railcar loading, trailer loading costs include backhoe and portable and fixed conveyor system (including feed and feedout bin) costs. Transport costs include truck trailer, driver, and fuel costs. Unloading costs are limited to the cost of constructing a temporary road into the disposal site.

The Detroit District uses unit costs between $1.30 and $2.50/yd[3]-mile ($1.07 to $2.05/m[3]-km) for preliminary estimates of truck trailer transport of dredged material (Wong 1994). The Chicago District estimated dump truck trailer unit costs (including truck trailer rental and labor) for 1-, 19-, and 32-mile (1.6-, 30-, and 51-km) haul distances to be $2.21/yd[3] ($2.91/m[3]), $11.25/yd[3] ($14.80/m[3]), and $17.80/yd[3] ($23.42/m[3]), respectively. They also estimated a unit cost of $2.72/yd[3] ($3.58/m[3]) to remove dredged material from a barge and place it into a truck trailer (Engel 1994).

Conveyor Transport

Souder et al. (1978) developed unit cost information for contracted belt conveyor transport of various dredged material haul volumes from a rehandling basin to a disposal site at various haul distances. This hypothetical operation involved using a bulldozer and backhoe to excavate the rehandling basin material and placing the material on a conveyor system that moved the material to the disposal site where it was dumped. The operation assumed that the conveyor was routed over flat terrain and that there were no costs associated with obtaining right-of-ways and other real estate.

Unit cost estimates for this hypothetical operation are provided in Figure 5-7. The operation costs include annual costs for loading and operating (energy and labor costs) a portable and fixed conveyor system. Conveyor loading costs include backhoe and bulldozer costs. Conveyors do not require additional equipment for unloading.

ESTIMATING CONTAMINANT LOSSES

There are a limited number of mechanisms for contaminant loss during the transport of contaminated sediments, and only one mechanism of contaminant loss can be predicted using *a priori* techniques (Myers et al., in prep.). Contaminant losses during loading and unloading operations are primarily the result of spills and volatilization. The amount of spillage during loading and unloading reflects the level of care taken by the operators and the efficiencies of any controls (e.g., drip aprons). Loading and unloading areas should be designed with systems to collect spillage and water used to wash transport vessels. This water should be routed to wastewater treatment systems. Contaminant losses from such treatment systems are discussed in Chapter 9, *Residue Management*.

Losses during transport are the result of leaks, volatilization, and accidental spills. The amount of leakage during transport reflects the containment efficiencies of the carrier vehicles. Accidental spills may occur as a result of equipment failure, operator error, or external influences (e.g., meteorological conditions). Although it is not feasible to entirely eliminate spills and leakage from transport systems for contaminated sediments, it is easier to design controls for these mechanisms of contaminant loss than to quantify them.

There is no *a priori* method for predicting the amounts of contaminants lost by spillage, leaks, and accidents from a transport mode. The only mechanism of contaminant loss that can be predicted is volatilization from transport systems without covers (i.e., barges, trains, trucks, and conveyors). Methods for predicting the loss of volatile and semivolatile organic contaminants from exposed sediments and ponded water have been developed, and are summarized in Myers et al. (in prep.). These predictive methods are almost entirely theoretical and have not yet been field verified.

MEMORANDUM

DATE: **August 28, 2012**

TO: **Jim Snider, Enbridge Energy, Limited Partnership**

FROM: **Bryan Rogne, AECOM**

Re: **Evaluation of Potential Floodplain Impacts and Proposed Operational Modifications for Containment Near MP 37.50**

1.0 INTRODUCTION

Enbridge Energy, Limited Partnership (Enbridge) installed surface boom and sediment curtains (Containment) in the Kalamazoo River upstream of Morrow Lake (near Launch E 4.0, and between mile post (MP) 37.00 and MP 37.75). The purpose of the Containment is to reduce downstream migration of potential submerged and floating crude oil. The temporary installation of the Containment is part of the release responses being performed by Enbridge in the Kalamazoo River. The locations of the Containment are shown in *Figure 1*.

Michigan Department of Environmental Quality (MDEQ) Permit # 12-39-0027-P for the Containment has the following condition:

> "Permittee shall provide MDEQ with an evaluation of potential floodplain impacts and backwater effects from installation of the Containment structures. Should it be determined that any portion of the permitted system causes a harmful interference per Part 31, Floodplain/Water Resources Protection of the Natural Resources and Environmental Protection Act, modifications to the structure shall be required."

This memo provides the evaluation of potential floodplain impacts of the Containment. The Hydrologic Engineering Center – River Analysis System (HEC-RAS) evaluation for the subject Containment determined that the permitted Containment may cause a harmful interference at a critical structure situated in the floodplain, upstream of the Containment located near MP 36.00. Therefore, this memo also specifies operational modifications to the Containment system that will eliminate the harmful interference and potential impacts to the critical structure resulting from Containment installation.

This memo includes the following sections:

- Description of reconfigured Containment,
- Evaluation of potential floodplain impacts,
- Containment release plan to minimize potential impacts to the critical structure, and
- Containment replacement criteria.

2.0 DESCRIPTION OF RECONFIGURED CONTAINMENT

The Containment design detail is shown in *Figure 2*. The Containment consists of a surface boom with a suspended oleophobic skirt and a 36-inch X-TEX sediment curtain held to the river bottom with a 1/2-inch ballast chain. The gap between the suspended skirt and the sediment curtain will allow water to flow through the Containment by allowing half of the water column to flow unimpeded. The Containment is configured to block a maximum of 50 percent of the water column in any water depth. The maximum height of curtain is 36 inches.

The surface boom portion of the Containment consists of a 6-inch diameter surface boom with a 6-inch oleophobic suspended skirt. A horizontal 5/16-inch cable at the top of the boom will hold the boom in place. The oleophobic skirt will be weighted down with a 5/16-inch ballast chain. Vertical nylon straps attached to the ballast chain at the bottom of the skirt by carabiner clips hold up the sediment curtain. The sediment curtain is a 36-inch high (maximum) X-TEX curtain suspended from the nylon straps and weighted to the bottom by a 1/2-inch ballast chain.

The Containment can be partially or totally released with the carabiner clips to reduce or eliminate the potential impacts of the Containment on the critical structure. Partial release will reduce the cross-sectional area of the Containment perpendicular to the flow. The straps between the surface boom and the sediment curtain are equipped with carabiners that allow the sediment curtain to be detached from the surface boom. The sediment curtain will then drop to the bottom, which will reduce the cross–sectional area of the Containment and impact of the Containment on upstream water levels.

Total release of the Containment may be done by releasing the sediment curtain and the downstream end of the surface boom (see *Figure 2*). This allows the sediment curtain to drop to the bottom and the released end of the surface boom to float downstream with the current. Total release of the Containment will eliminate impacts of the Containment on water surface elevations.

3.0 EVALUATION OF POTENTIAL FLOODPLAIN IMPACTS

The *Kalamazoo River Hydrologic Engineering Center – River Analysis System (HEC-RAS) Model* (AECOM, 2011) was used to estimate river flows with potential to impact a critical structure located in the 100-year floodplain approximately 1 mile upstream of the Containment. The location of the critical structure in relation to the 100-year floodplain and the locations of the Containment and monitoring staff gage are shown in *Figure 1*. The critical structure is a residence with a first floor elevation of approximately 778 feet above mean sea level (amsl). The downstream boundary condition during the modeling was a water surface elevation of 775 feet amsl at the Morrow Lake Dam spillway. The Morrow Lake Dam is a hydroelectric facility that maintains a normal water surface elevation on Morrow Lake of 775 feet amsl. Kalamazoo River flow data are available from the United States Geological Survey (USGS) gaging station located at Battle Creek (Station 04105500) (Battle Creek), located in Battle Creek upstream of Morrow Lake Delta.

The model was used to estimate river flow in cubic feet per second (cfs) that may result in the critical water surface elevations near the critical structure. Four model scenarios were created in the HEC-RAS model, and the results are presented below:

- <u>Scenario 1</u>: Estimates the flow above which the critical structure will potentially be impacted with no Containment in place. The critical elevation is 778 feet amsl, which is the approximate elevation of the critical structure derived from Light Detection and Ranging (LiDAR) data with 1-foot contour intervals. The model estimates that the critical structure may be impacted at river flows of 1,430 cfs, which has a recurrence interval of 1.05 years, with no Containment in place. This means that any flow obstruction in the river has potential to impact the critical structure.
- <u>Scenario 2</u>: Estimates the flow above which the critical structure will potentially be impacted with the Containment fully deployed. The critical elevation was set to 777.5 feet amsl, slightly less than the elevation of the critical structure in order to provide a safety margin. The model estimates that the water surface elevation at the critical structure will be 777.5 feet amsl at river flows of 1,030 cfs.
- <u>Scenario 3</u>: Estimates the flow above which the critical structure will potentially be impacted with the Containment partially released. The critical elevation was set to 777.5 feet amsl, slightly less than the elevation of the critical structure in order to provide a

safety margin. The model estimates that the water surface elevation at the critical structure will be 777.5 feet amsl at river flows of 1,120 cfs.

- Scenario 4: Estimates the impact of releasing the Containment in the mainstream (locations C, D, E, and F, shown in *Figure 1*) only, compared to release of all of the Containment. This scenario found that release of just some of the Containment had similar impacts as the release of all the Containment on water levels at the critical structures. This scenario was not used in the Containment release plan (*Section 4.0*) because model estimate impacts to the critical structure if the mainstream Containment is released showed that impacts do not decrease because the backwater containment (at location A and B) remains in place.

The models are identical except for the critical elevations (identified above) and the addition of obstructions to represent the flow obstruction of the Containment. The critical elevation was set to the first floor elevation of the critical structure (approximately 778 feet amsl).

The model provides estimates that are limited by available topographic and bathymetric data. Therefore, the modeled flow estimates will be used as triggers for actual water level monitoring near the critical structure. Actual water levels near the critical structure will be used to trigger release of the Containment.

These results for scenarios 1 through 3 are summarized in *Table 1*.

4.0 CONTAINMENT RELEASE PLAN TO MINIMIZE POTENTIAL FOR IMPACTS TO CRITICAL STRUCTURE

The goal of this plan is to specify monitoring procedures and conditions that will trigger release of the Containment to prevent the Containment from contributing to flooding impacts at the critical structure. Flooding impacts to this structure may still occur due to river flows not influenced by the Containment.

This Containment release plan specifies monitoring real-time flow at Battle Creek and monitoring water surface elevations at the critical structure staff gage to be installed by Enbridge upstream of the 35th street Bridge. The Containment will be released when water levels exceed certain thresholds as discussed in scenarios 1 through 4 in *Section 3.0*. Releasing the Containment will prevent flooding impacts at the critical structure potentially due to the

Containment. The plan includes partial or total release of the Containment, depending on the flow and water level elevations observed at the monitoring staff gage.

River flow at Battle Creek will be monitored daily. Water levels at the critical structure staff gage in the river near the 35th Street Bridge will be monitored every six business hours or more frequently if the river flow exceeds 1,030 cfs at Battle Creek. The critical structure staff gage will be located on the left descending bank upstream of the 35th Street Bridge, which is located approximately 1/2 mile downstream of the critical structure. The location of the staff gage in relation to the critical structure is shown in *Figure 1*.

Release of the Containment will be initiated if the water surface elevation at the staff gage reaches or exceeds 777.5 feet amsl. The release will be done in a sequence (see Steps 1 through 4 below) intended to keep the Containment in place to the extent consistent with protection of the critical structure. *Section 5.0* specifies conditions for replacing the Containment.

Step 1: The mainstream Containment (locations C, D, E, and F, shown in *Figure 1*) will be partially released if the staff gage elevation exceeds 777.5 feet amsl. The straps (fitted with carabiners) between the surface boom and the sediment curtains will be released to detach the sediment curtains from the surface boom. The surface boom will remain in place. The sediment curtains will drop to the bottom of the river, reducing the impact of the sediment curtains on water levels at the critical structure.

Step 2: The mainstream Containment will be completely released if the staff gage elevation continues to exceed 777.5 feet amsl, or if significant rainfall is predicted that could cause elevations to continue to rise. The cables attaching the downstream ends of the Containment will be released, allowing the surface boom to remain anchored at the upstream end while not obstructing any flow thus reducing the cross sectional area perpendicular to river flow.

Step 3: The backwater Containment (locations A and B, shown in *Figure 1*) will be partially released (as described above) if the staff gage elevation continues to exceed 777.5 feet amsl, or if significant rainfall is predicted that could cause elevations to continue to rise.

Step 4: The backwater Containment will be completely released if the staff gage elevation continues to exceed 777.5 feet amsl, or if significant rainfall is predicted that could cause elevations to continue to rise.

In some cases it may be prudent to increase the monitoring frequency before the critical structure staff gage elevations exceed 777.5 feet amsl. For example, if the flows and water levels are increasing and expected to continue to increase due to recent or predicted precipitation (or snow melt), it may be prudent to release the Containment before the critical structure staff gage elevation exceeds 777.5 feet amsl. Careful and frequent monitoring of the staff gage is required to implement this plan. It is anticipated that the release of the Containment in the steps outlined above may need to be done in a fairly quick succession.

Attachment A is a log for recording flows from Battle Creek and water levels at the critical structure staff gage located upstream of the 35th street bridge. The daily flow at Battle Creek can be obtained at http://waterdata.usgs.gov/usa/nwis/uv?04105500. The "Most Recent Instantaneous Value" and the corresponding time from this website will be recorded on the log.

Water levels at the critical structure staff gage will be monitored at least every six hours or more frequently when the flow at Battle Creek exceeds 1,030 cfs. The logs will be completed as long as the Containment is in the river, regardless of whether the Containment is released. Appropriate notes regarding weather forecasts, release of the Containment or other relevant information will be recorded on the form.

5.0 CONTAINMENT REPLACEMENT CRITERIA

The Containment may be re-attached when the following conditions are met:

- The water level at the critical structure staff gage is less than 777.5 feet amsl,
- The flow at Battle Creek is less than 1,030 cfs, and
- The weather forecast is favorable (no significant rain or snow melt in drainage area upstream of Battle Creek is forecast for the next 10 days).

6.0 REFERENCES

AECOM (2011). Kalamazoo River Hydrologic Engineering Center-River Analysis System (HEC-RAS) Model.

Figures

ENBRIDGE

Drawn: TG 8/24/2012
Approved: GH 8/24/2012
Project #: 60246209

Map Location

Legend

- Anchor Points
- 100 Year Kalamazoo River Floodplain Boundary
- Backwater Containment Location
- Mainstream Containment Location
- Quarter Mile Grid Segments
- Staff Gage Location

N

0 400 800 1,600
Scale in Feet

FIGURE 1
LOCATION MAP
MP 35.75 to MP 38.00
PERMIT # 12-39-0027-P

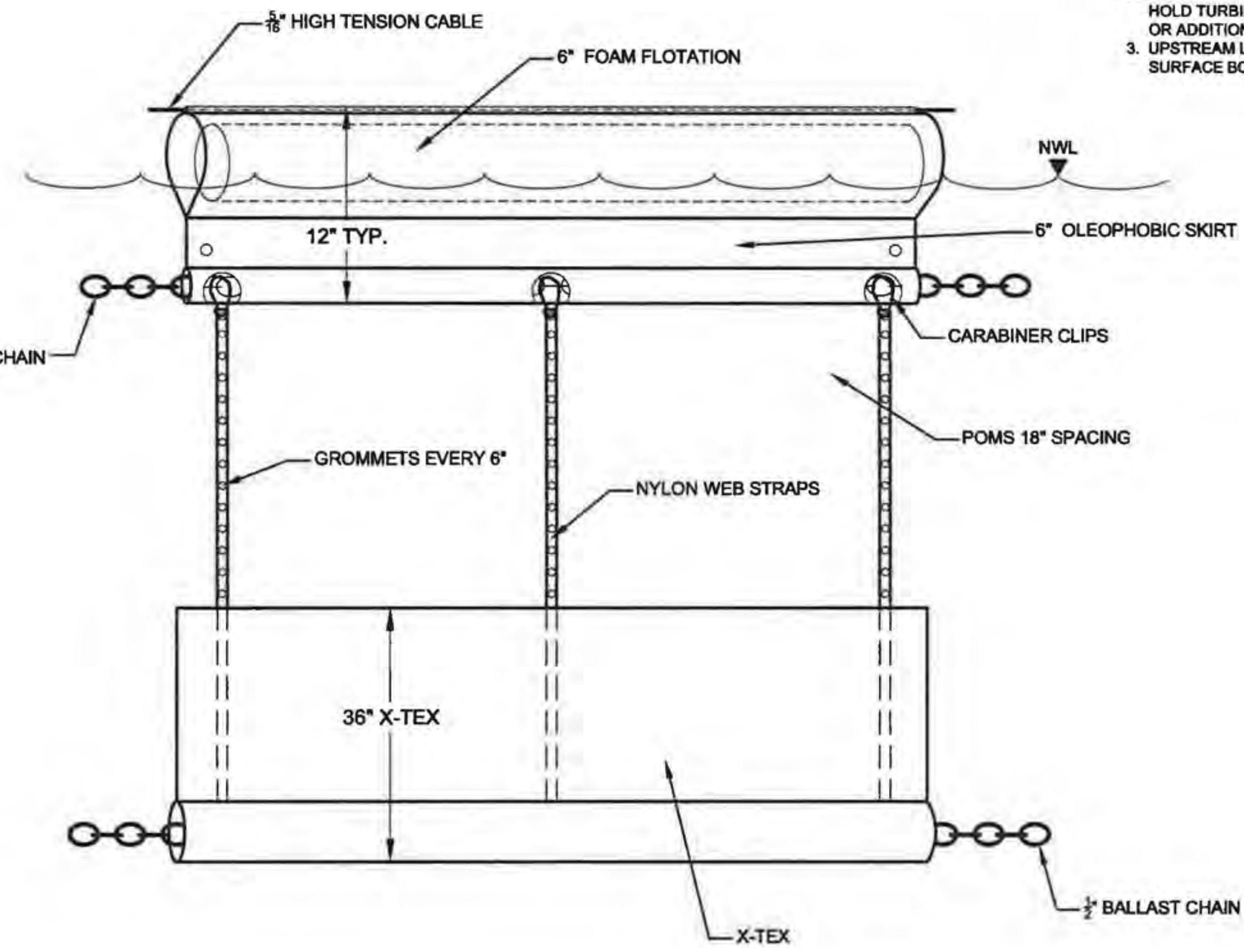
ENBRIDGE LINE 6B MP 608
MARSHALL, MI PIPELINE RELEASE
ENBRIDGE ENERGY, LIMITED PARTNERSHIP

Z:\Work\GIS\AECOM_Templates\2012\11x17_Landscape_Template_120411.mxd

Aerial Photography Date: April 2011

12 " SURFACE CONTAINMENT BOOM WITH 36" X-TEX PARTIAL BOTTOMLAND CURTAIN DETAIL

NOTES:
1. CONTAINMENT BOOM SECTIONS JOINED USING 12" ASTM CONNECTION.
2. SHOULD ADDITIONAL BALLAST BE NECESSARY TO HOLD TURBIDITY CURTAIN IN PLACE, CINDER BLOCK OR ADDITIONAL CHAIN MAY BE UTILIZED.
3. UPSTREAM LOCATION D CURTAIN TO HAVE ONLY SURFACE BOOM.



ENBRIDGE

Drawn: WL 06/19/2012

Approved: MZ 06/19/2012

Project #: 1008114.00

MAP LOCATION

LEGEND

NOT TO SCALE

FIGURE 2

E 4.0 CONTAINMENT BOOM RECONFIGURATION DETAILS

ENBRIDGE LINE 6B MP 608

MARSHALL, MI PIPELINE RELEASE

ENBRIDGE ENERGY, LIMITED PARTNERSHI P

Table

Table 1. Model Scenarios and Estimated River Flows at Critical Elevations
Enbridge Line 6B MP 608 Marshall, MI Pipeline Release
Enbridge Energy, Limited Partnership

Model Scenario	Critical Elevation at Critical Structure (feet amsl)	Flow at Battle Creek Gage Corresponding to Critical Elevation (cfs)
1. No Containment in Place	778.0	1,430
2. Containment Fully Deployed	777.5	1,030
3. Containment Partially Released	777.5	1,120

amsl = above mean sea level
cfs = cubic feet per second

Attachment A

River Flow and Water Level Elevation Log

Attachment A. River Flow and Water Level Elevation Log
Enbridge Line 6B MP 608 Marshall, MI Pipeline Release
Enbridge Energy, Limited Partnership

Date	Time	River Flow at Comstock Gage (cfs) (1)	Water Elevation at Staff Gage (feet amsl) (2)	Comments

(1) Instantaneous flow readings available at http://waterdata.usgs.gov/usa/nwis/uv?04106000.
(2) Staff gage readings required if flow at Comstock gage exceeds 1,300 cfs.