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Preliminary Tunnel Evaluation

Proposed Detroit River International Crossing

CS 82900 – JN 802330

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1. Introduction

The purpose of this report is to evaluate the tunnel requirements and feasibility for the Illustrative Alternative evaluation of the Detroit River International Crossing Study. The preliminary crossing locations are presented in Figure 1. This document divides the length of the river into three broad geographic sections where the geotechnical conditions are similar with respect to tunneling issues (Figure 2):

- Southern Section – from Grosse Isle to south of Zug Island (Sta. 0+00 to 100+00)
- Central Section – from south of Zug Island to Detroit River Rail Tunnel (Sta. 100+00 to 200+00)
- Eastern Section – from Detroit River Rail Tunnel to Belle Isle (Sta. 200+00 to 300+00)

This report also examines the roadway requirements for a tunnel, appropriate tunnel types, state-of-the-art tunnel construction techniques, and engineering considerations. It ends with conclusions about the practical feasibility of tunneling under the Detroit River in the DRIC Study corridor.

2. Tunneling

2.1. Roadway Requirements

The Detroit River Crossing roadway is expected to six (6) lanes (corresponding to three lanes in each direction) with shoulders or offsets depending on the traffic and operational demands. It is assumed that the lanes would be evenly divided between tunnel sections or bores. Each lane will be 3.6 m (12 feet), with a minimum 0.6 m (2 foot) offset on each side for a three-lane roadway width of 12 m (40 feet) in each direction.

These dimensions represent the minimum internal road surface width of the tunnel cross sections. The internal height, from roadway surface to the top of the tunnel, will be 5.0 m (16.4 feet), across the entire internal road surface width. As such, the minimum requirement will be a tunnel cross section that encompasses a rectangular “traffic” area 12 m (40 feet) wide by 5.0 m (16.4 feet) high.

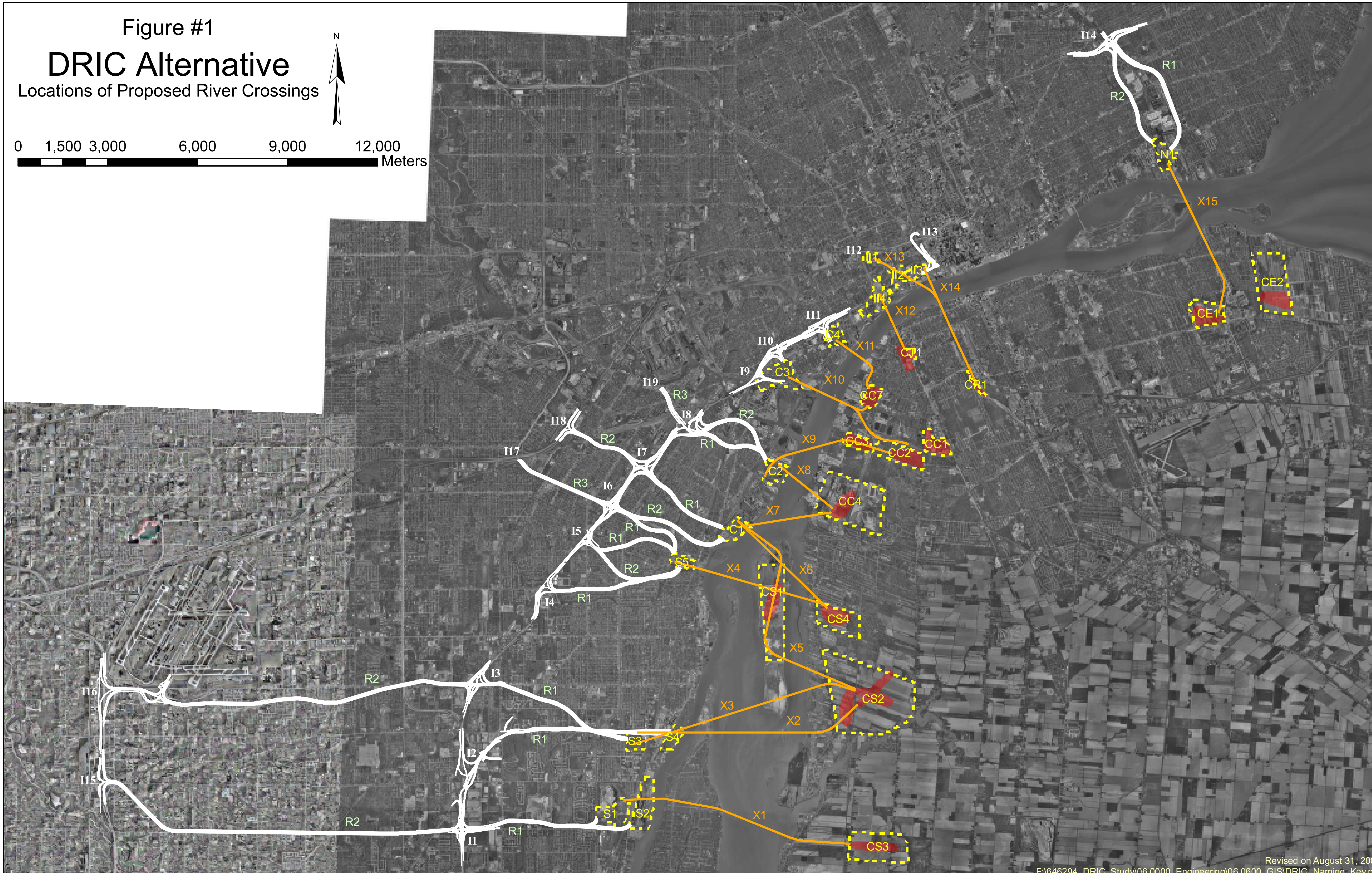
These internal dimensions do not include areas required for pedestrian egress, ventilation, and utilities. For a bored tunnel (which will involve a round tunnel section), such items can be included in the areas outside the rectangular “traffic” area. For a submerged tunnel (which would typically be any desired cross section), such items would need to be incorporated inside the tunnel, in addition to the rectangular “traffic” area.

For the three-lanes-in-each-direction using twin tunnel bores, the external diameter of each bore would be approximately 15.4 m (50.5 feet), which is at the extreme high end of tunnels that have been constructed in soft ground (world-wide). To accommodate

Figure #1

DRIC Alternative

Locations of Proposed River Crossings



Revised on August 31, 2005

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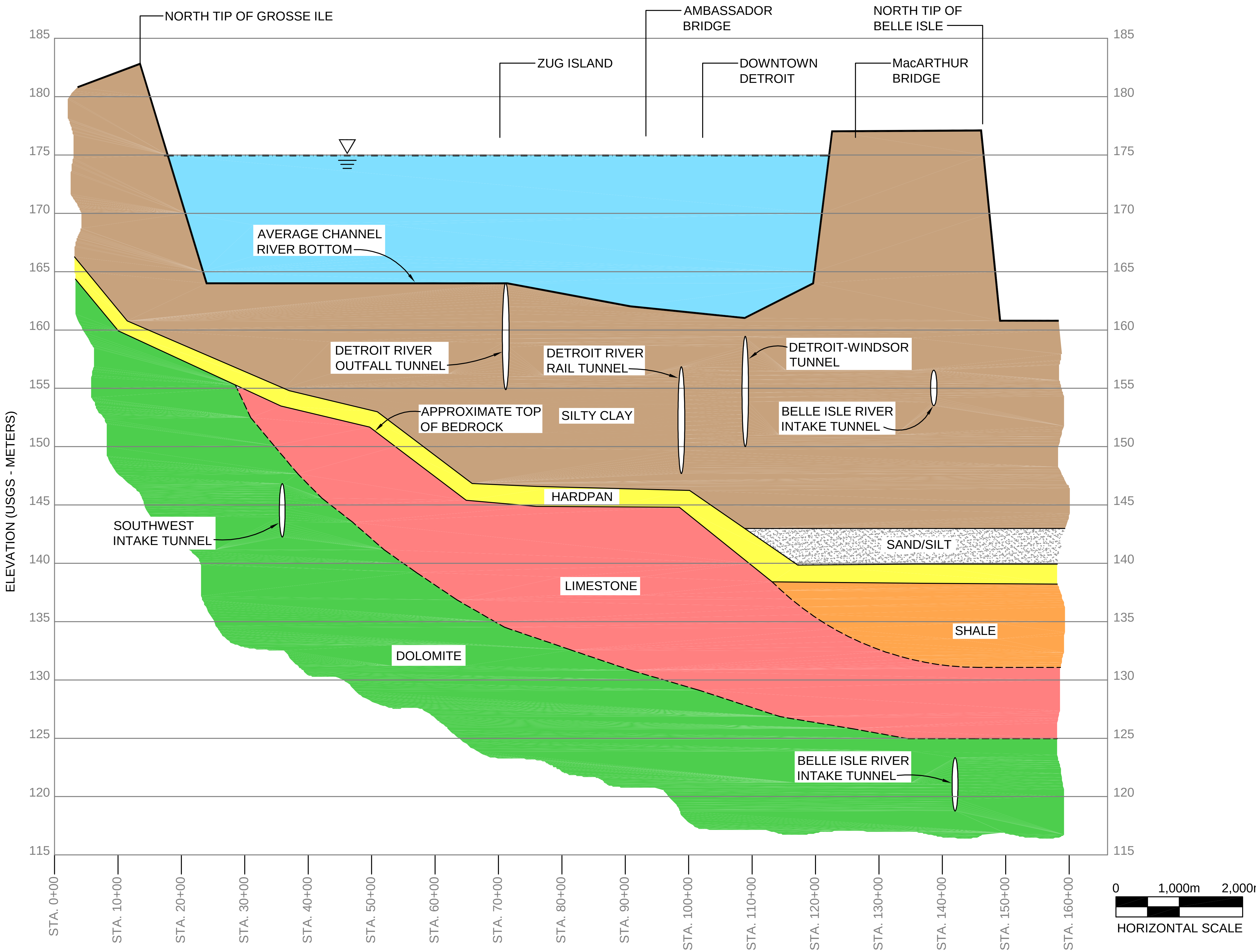

NTH Consultants, Ltd.
Infrastructure Engineering and Environmental Services

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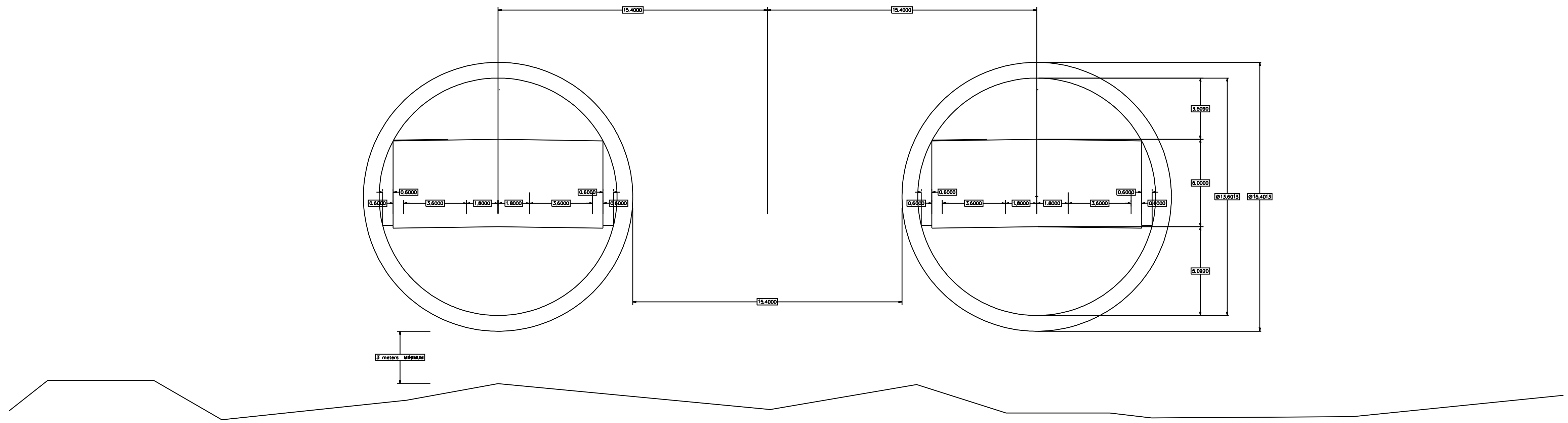
DESIGNED BY: CRJ
DRAWN BY: SHB
CHECKED BY: JBA

CROSS SECTION ALONG RIVER

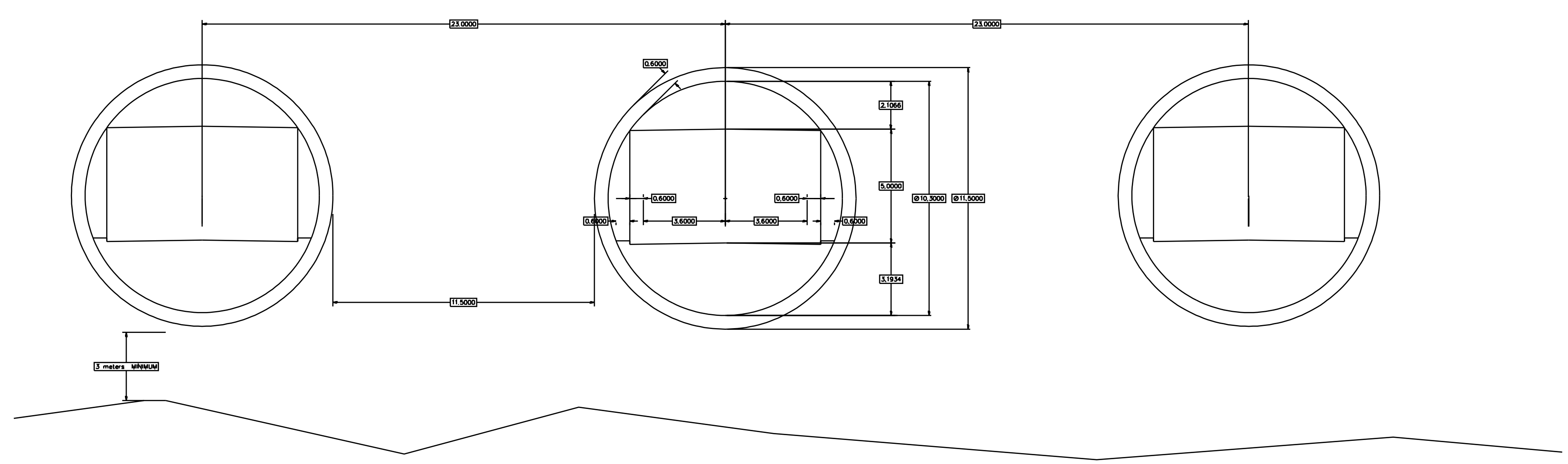
DETROIT RIVER INTERNATIONAL CROSSING
DETROIT, MICHIGAN - WINDSOR, ONTARIO

FIGURE No.
2

Figure #3
Tunnel Cross Sections



15.4 m BORE, DOUBLE–TUNNEL



11.5 m BORE, TRIPLE–TUNNEL

three-lanes-in-each-direction with two-lane tunnel bores three 11.5 m (37.7 feet) bores would be constructed. See Figure 3 above for bored tunnel cross section.

2.2. Tunnel Types and Construction Techniques

Tunneling can be generally discussed in terms of hard rock tunneling and soft ground tunneling. For this project (and for the purposes of discussion herein), hard rock tunneling would be through limestone and/or dolomite, while soft ground tunneling would be through soft to medium clay and, in some areas, sand/silt. The specific geotechnical conditions will be discussed in more detail in later sections of this report.

A separate technique from bored tunneling involves the use of an immersed tube installed into an open cut trench across the river bottom.

2.2.1. Rock Tunnels

Hard rock tunneling involves the use of modern drilling and blasting or the use of a tunnel boring machine (TBM) to disintegrate and remove rock within a prescribed boundary along a pre-determined alignment. Geological and geotechnical investigations must be sufficiently comprehensive to assure safe, continuous progress of excavation and rock support during construction. Particular attention must be paid to shear zones, faults, water and noxious gas regimes along the tunnel corridor as well as the magnitude of potential settlements in overburden soils.

Tunnels constructed in hard rock, Greece

The discussion here of hard rock tunnelling focuses on tunnelling through high permeability (greater than 10-4 cm/sec) limestone and/or dolomite.

In modern 'hard rock' tunnelling, and increasingly in 'soft rock' tunnelling, the primary support (for the immediate stabilization of the rock mass at the work face) is often incorporated into the permanent support, thus improving time and cost efficiency. This is typically the case with tunnelling methods and rock formations that do not require installation of a tunnel lining immediately behind the mining face.

As a better understanding about the utilization of the self-bearing capacity of the rock mass was gained in various tunnelling projects worldwide, the concept of reinforcing the rock mass (rather than supporting it) developed. Fully grouted reinforcing bars support the rock mass. Fibre–reinforced, sprayed concrete can also reinforce the rock surface by restricting the movement of rock fragments.

Tunnelling experience indicates it is essential to make adjustments to a tunnel's design according to observations about how the ground behaves. For example, in some situations, observations may confirm that a stiff support needs to be installed as soon as practically possible, to avoid unsafe loosening of the ground. Besides visual observations, monitoring deformations is also conducted, in order to decide whether supplementary support is necessary.

The type and quantity of rock support is also determined based on *observation* of the main features and behavior of the ground: such as rock types; orientation, frequency and smoothness of jointing, occurrence of water, presence of clay and signs of swelling, etc. Rock mass characterization or classification systems [like RMR (Bienawski), Q (Barton et al, Norwegian Geotechnical Institute, NGI)] can be useful in obtaining a systematic assessment of the rock mass quality. Data can then illustrate the normal level of rock support, for comparison.

Numerical simulation can be a useful tool in the design process, but cannot substitute for practical experience. If the type and level of rock support is chosen based on experience or 'rock support classes', numerical simulation may demonstrate typical levels of resulting deformations, which may be compared to actual deformations during excavation. Numerical simulation (e.g. by Universal Distinct Element Code (UDEC)) may demonstrate the effects of earthquakes or weapon loads on a reinforced underground structure. Although modern software is powerful, it is important to remember the critical importance of obtaining quality input parameters and of applying the computer predictions with caution. Other limitations are associated with the difficulty of realistic simulation. (e.g. accurate simulation of three-dimensional sets of joints).

Drilling and blasting (D&B) provides a flexible method of tunnelling, which can easily be adapted to varying ground conditions. This method of tunnelling should normally be characterized by site investigations ahead of the face by probe drilling, an active approach to the rock support decision process at tunnel face, and the use of modern high-capacity equipment for all operations and selective rock support to suit the rock mass conditions.

D&B in hard rock usually consists of systematic rock bolting, robotically applied fibre reinforced shotcrete in accordance with prescribed rock mass quality classification systems (e.g. RMR, Q-value), supplemented by numerical modelling (e.g. by UDEC). In softer rocks, steel arches or lattice girders are often needed to provide support.

D&B and conventional TBM mining in higher permeability rock necessitates pre-treatment of the rock mass ahead of the tunnel bore to reduce the effective permeability and associated water inflow into the tunnel. Use of probe drilling and grouting equipment is important where control of the water regime around the tunnel is needed, whether it is for sub-sea tunnels or for tunnels in urban environments where unacceptable settlements could be induced in the overburden soils. Hard rock Tunnel Boring Machines (TBM) should also be equipped with probe drilling and grouting equipment in similar circumstances or if voids, vugs and karstic features are anticipated.

In the case of tunnel boring, it is more difficult to incorporate probe drilling and pre-grouting (pre-excavation grouting), due to limited space. It is therefore very important that the TBM be designed to accommodate such work, should there be a possibility that it may be needed.

Reinforcement for Concrete Lining

Probe drilling may be supplemented by geophysical probing ahead of the tunnel face, which has been developed into a practical method that does not significantly interfere with the other activities. Core drilling is time consuming and is rarely used unless more complete information on the rock mass is needed. Modern tunnel pre-grouting techniques and materials now make it possible to obtain the required water-tightness in a cost-effective manner.

However, in the case of tunnels constructed under the sea or rivers, water inflow from the surrounding rocks is often difficult to predict. Numerical simulations may be useful, but need to be carefully calibrated. There is no substitute for practical experience and expertise in such circumstances.

Hard rock tunnels normally have a cast-in-place reinforced concrete lining constructed inside the permanent rock-support lining placed after the D&B operation. A geo-membrane is normally placed between the inner and outer linings, as shown in the photographs immediately above and below.

Waterproof Membrane and Portal Construction

TBM excavation is generally the preferred method in urban areas and is often more cost-effective than D&B methods for long tunnels in rural areas. Nonetheless, the economic advantages of increased tunneling performance can only be fully exploited by proper design of the Tunnel Boring Machine. A range of machines is available, which can be generally classified according to working face support as well as method of spoil conveyance and disposal.

The shielded hard rock TBM (see photograph below) performs at its best in brittle rock, soft rock and varying tunnel formations. Under protection of the shield, the tunnel is excavated and lined in segments. This procedure enables a high and continuous tunneling performance even in heterogeneous conditions and with large diameter tunnel bores.

An emerging technology for tunneling in higher permeability rock involves the use of a pressurized, slurry-face TBM. For such a machine, pre-grouting of the rock mass is not necessary, and the water pressure at the mining face is resisted by maintaining a pressurized chamber of slurry. As the mining advances and the TBM cutting face produces rock chips and mining spoil, the spoil/slurry mix is pumped out of the pressurized chamber at the face, the slurry and mining spoil are separated, and the clean slurry is pumped back through the system. Because the permeability of the rock mass is not reduced, a segmental, gasketed tunnel lining is erected immediately behind the mining face. The segmental tunnel lining serves as both the immediate tunnel support and the permanent lining.

Dublin Port Access Tunnel, 11.7 m hard-rock TBM

2.2.2. Soft Ground Tunneling

Soft ground tunneling machines have become more sophisticated in recent years. The introduction of pressurized-face TBM's, including Slurry Shield Machines and Earth Pressure Balance Machines, have resulted in tunnels being constructed in ground conditions which had previously been too difficult to tackle using more conventional methods. These machines are routinely used today to build tunnels in soft ground such as water-bearing sands and gravels.

The Earth Pressure Balance machine is a shield machine with an earth pressure balanced working face. The soil extraction takes place via the cutting wheel. For shield tunneling in soil which is not stable, a loss of stability at the working face is prevented by creating supporting pressure. With the earth pressure shield, in contrast to the other shields which rely on a secondary support medium, the soil loosened by the cutting wheel serves to support the working face.

In the case of the Slurry Shield Machine, where geological conditions with an unstable working face or mixed geology is expected, the extraction chamber is filled with a pressurized liquid suspension material. The pressure chamber behind the submerged wall supports the suspension with a compressed air buffer. The air pressure is automatically monitored by an adjustable compressed air regulator in order to prevent blow-outs or ground seepage on the working face. If the geological conditions are such that a stable working face is expected, e.g. in hard rock or cohesive soil, the machine can be effectively used as a slurry shield without compressed air support.

Specialist advice on machine selection should be sought and recommendation regarding the machine design for the given ground conditions should be supported by the TBM manufacturer. The choice of machine for soft ground conditions, whether a Slurry Shield Machine or an Earth Pressure Balance Machine mainly depends on the soft ground conditions. However, appropriate machine design refinements may be used to extend the indicative grain size distribution limits shown in the following grain size distribution chart and to encompass other ground conditions.

Bored tunnels advanced using pressurized-face methods are generally supported with a single shell of ring-shaped, steel reinforced lining segments using the protection of the shield. A remote controlled crane (erector) in the backup system uses vacuum suction plates to lift the preassembled parts and position them next to each other in an exact fit. With the tunneling jacks, which are supported by the finished tunnel rings, the shield is moved far enough forward for another tunnel ring to be installed. During the forward movement of the tunneling machine, the gap between the ground and the tunnel lining is injected with cement grout. This grouting is carried out to prevent the penetration of ground water and soil and to stabilize the soil above the tunnel.

In order to prevent the penetration of ground water, the ring joints and parallel joints of the single-shell tunnel supported with lining segments are sealed with a neoprene band which is pulled into a circulating groove during production and then fixed. The sealing takes place by pressing the seal profiles together. The necessary force is applied in the ring joints by the tunneling jacks of the shield and in the parallel joints by the installation of a wedge-shaped cap stone and the grouting of the ring gap.

2.2.3. Submerged Tunnels (Immersed Tube Tunnels)

Submerged tunnels have been constructed as appropriate cost-effective alternatives to bored tunnels at several similar locations in the United States and worldwide. Concrete tunnel elements are conventionally constructed in a casting basin below sea level, which is then flooded to float the elements (with bulkheads at ends) into position over a prepared foundation on the riverbed. Each element is divided into segments. Temporary longitudinal pre-stress is applied to the element roof and base slabs to deal with conditions during tow-out and immersion.

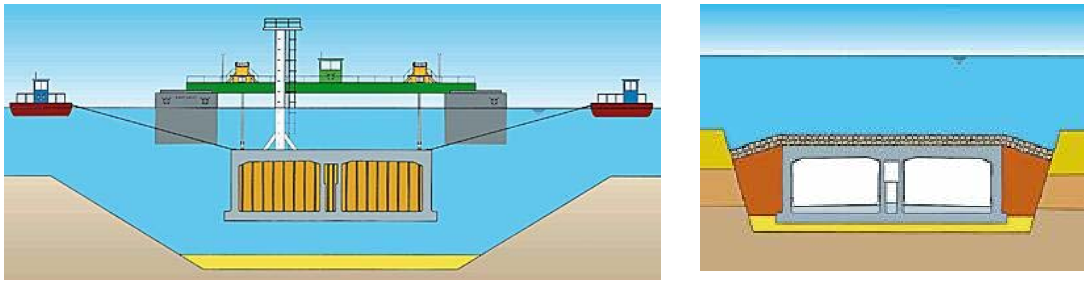
Submerged Tunnel Elements and Bulkheads

The cross-section is designed against hydrostatic uplift, which normally determines the thickness of the roof, base and wall slabs. The tunnel is also designed to accommodate the required traffic and ventilation systems. The cross-section is designed so that each segment (some 100m long) can be floated to the tunnel site. After installation, additional backfill is placed on top of the tunnel to increase the factor of safety against uplift forces.

Elements prior to flooding of lagoon and launch

The joints between elements are each provided with two seals and each segment joint normally incorporates a groutable waterstop and a hydrophilic seal for watertightness. The key to success is correct sealing of the tunnel against water pressure. Sealing against water pressure between the elements of an immersed tunnel is normally accomplished by proprietary seals, which are used worldwide for such applications.

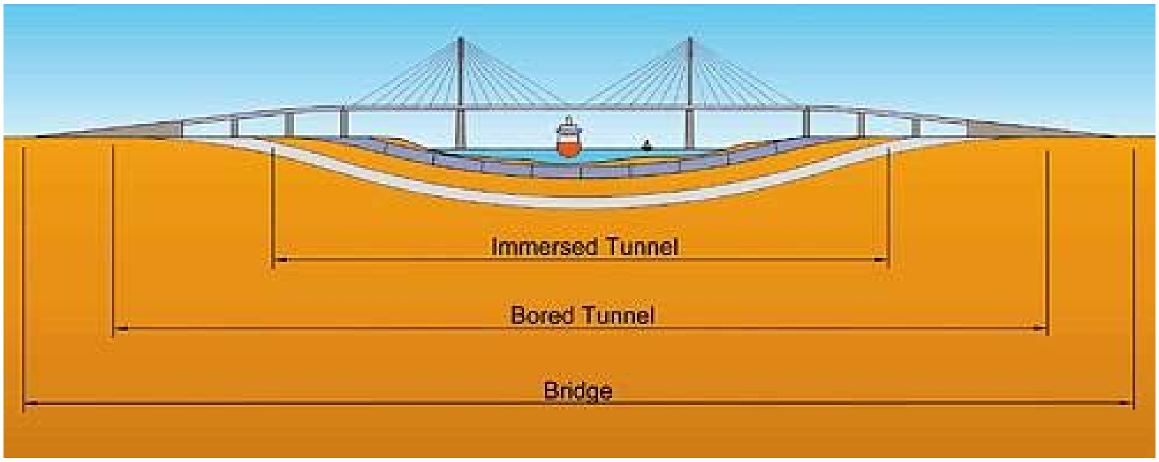
Submerged Tunnel Seal



Graphic indicating submerged tunnel installation method

Due to water pressure differences, between the bulkheads and the hydrostatic pressure on the outside of the tunnel, the seal material compresses and, as a result of this, the joint is sealed. A secondary permanent seal is then clamped across the joint on the inside. In general, the bulkheads are removed after approval of the pressure test between the two proprietary seals.

Element on tow to submerged tunnel site

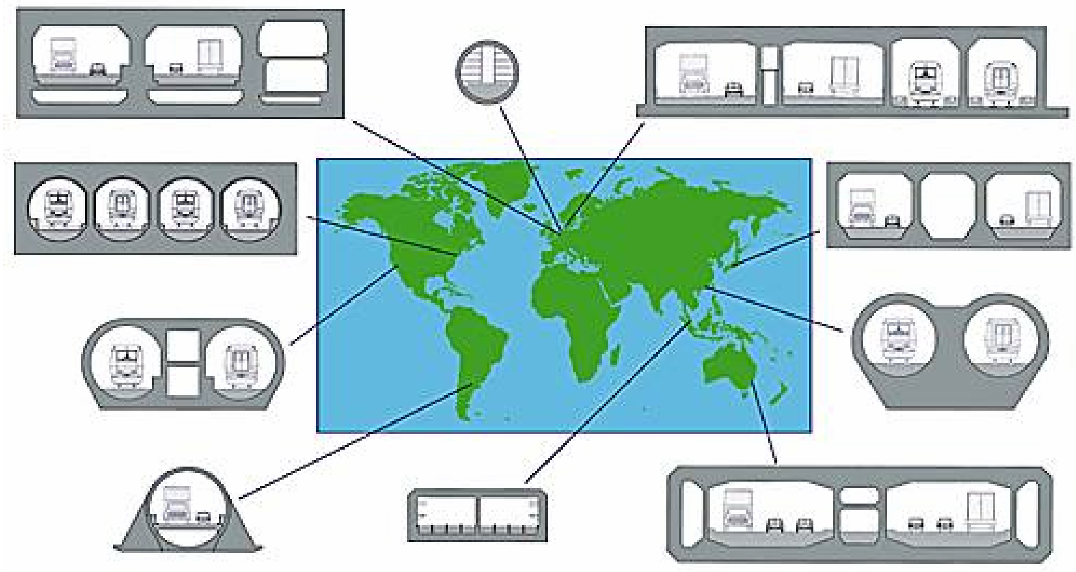


River Crossing Types

The three types of river crossing that are commonly used today, which are illustrated in the above graphic, are as follows:

- Bridge Crossing
- Tunnel crossing excavated by soft or hard ground tunneling methods
- Submerged or Immersed Tunnel crossing

Note that the length of a submerged tunnel is normally significantly less than the bridge alternative because the bridge must be elevated to provide sufficient clearance for river traffic. Tunnels excavated by mining methods (e.g. drilling and blasting) are generally constructed in rock below the overburden and, unless the rock surface is at shallow depth, need to be significantly longer than the alternative submerged tunnel to comply with roadway design gradients. However, if the overburden ground appears suitable, shallow tunnel construction in the overburden using slurry shield or earth pressure balance machines may apply. Suitable location for tunnel portals and dry-dock or similar facility for tunnel elements' manufacture should be identified at an early stage in the conceptual design of submerged tunnels.



Graphic illustrating typical submerged tunnel cross-sections

It is important to note, as illustrated in the graphic above, that the cross-section selected for the submerged tunnel can be large enough to accommodate three or more lanes of traffic in each direction and may include different modes of transportation.

3. Geotechnical Considerations

3.1. General River Soil/Rock Profile

Generalized soil and rock profile along the center line of the river in the DRIC Study corridor are presented in Figure 2. The southern section of the alignment is expected to present bedrock at approximately Elevation 152 to 158 m (498 to 520 feet). Soil cover over the bedrock is soft to stiff silty clay with approximately 1 m (3 feet) of hardpan soil directly over the bedrock. The bottom of the Detroit River is on the order of Elevation 168 m (550 feet) resulting in soil cover over the rock on the order of 7 to 13 m (20 to 40 feet) in the navigation channel areas of the river. Bedrock consists of dolomite and limestone in the upper regions.

In the center of the corridor at the general vicinity of the existing Ambassador Bridge, Limestone bedrock is expected at a surface elevation of 148 to 150 m (486 to 492 feet). Approximately 1 to 2 m (3 to 6 feet) of hardpan is present over the bedrock. The bottom of the Detroit River is expected to be on the order of Elevation 163 m (535 feet), resulting in soil cover of approximately 15 m (40 feet) over the bedrock. Soft ground soils generally consist of medium to stiff silty clay on the United States side of the Detroit River while historical data indicate that, on the Canadian side, the lower approximately 12 m (40 feet) of soil over the hardpan is dense sand and sandy silt. Thicker zones of sand and sandy silt may be present on the Canadian side of the central zone.

Bedrock dips significantly to the eastern end of the corridor where Traverse Group and Antrim Shale is expected at the far east end Elevations 137 to 140 m (450 to 460). Hardpan soil cover of approximately 3 to 7 m (10 to 25 feet) is present over the bedrock. The bottom of the river navigational channel is on the order of Elevation 165 m (540 feet) resulting in soil cover of 18 to 25 m (60 to 82 feet). Soil overburden consisting of medium to stiff silty clay on the United States shore is expected, while approximately 3 to 4 m of sand (10 to 15 feet) has been noted over the hardpan on Belle Isle in some historical borings.

A separate consideration from the near surface soil and rock conditions, is the presence of sizable salt formations at depths of 300 to 400 m (1,000 to 1,300 feet) in the Detroit and Windsor areas. Salt has been historically mined using both conventional room-and-pillar excavation and by solution mining methods. Salt has been mined either directly in solid form as rock salt or as natural or artificial brine pumped through solution mining wells. Room-and-pillar mining involves excavation of salt by miners using traditional mechanical mining techniques. As the salt is mined pillars are left in place to maintain the stability of the mined cavern.

In general, solution mining consists of introducing water from the surface down a well casing between the outer casing and a central tube. The brine produced from the salt dissolving in the water is recovered through the central tube. Cavities in the ground are formed using this method, and can sometimes cause sagging, downward flexure, and local separation of rock units resulting in local “ground roof” roof collapse and eventual ground surface subsidence.

Several areas of salt mining along the proposed crossing corridor that are known to have impacts potentially affecting proposed tunnel crossing scenarios include Zug Island, several mining operations in the Delray area, at Point Hennepin on Grosse Isle, and several other locations downriver. In addition, several historical and current solution mining operations are known on the Canadian side.

3.2. History of Tunneling Efforts

Nine major tunneling efforts beneath the Detroit River in the proposed tunnel corridor area are available for review. Of these, two tunnels, The Detroit/Windsor Car Tunnel (1930) and the Detroit River Railroad Tunnel (1910) were built beneath the river in soft ground using cut and cover/submerged tube methods. Both of these are generally located in the center of the corridor under study. For this construction type, a trench was excavated in the river and pre-cast tunnel sections were sunk in the trench. The sections were connected by divers and backfilled. The car tunnel structure width has an exterior dimension of 10.7 m (35 feet) and the railroad tunnel has a width of 15.5 m (51 feet).

The Southwest Intake Rock Tunnel, Detroit River Outfall Tunnel No. 2 (DRO-2), and Belle Isle 16 foot diameter rock Intake Tunnel were built beneath and near the river within bedrock. The Southwest Intake Rock Tunnel and DRO-2 are located in the southern portion of the corridor and the Belle Isle Tunnel is located at the eastern end.

The Southwest and Belle Isle tunnels were built by the drilling and blasting technique, while the DRO-2 was recently built using an open atmosphere Tunnel Boring Machine. The diameters of the tunnel bores varied from 3.7 m (12 feet) to 6.4 m (21 feet). Each tunnel experienced significant inflows of hydrogen sulfide-bearing groundwater and required great efforts to control the water and hydrogen sulfide gas. Extensive grouting and ventilation were required. The DRO-2 tunnel was abandoned due to water and gas infiltration.

Four tunnels were constructed in soft ground and consist of the Southwest Intake Land Tunnel, the Detroit River Outfall Tunnel (DRO-1), the Belle Isle 10 foot diameter Intake Tunnel, and an 1874 tunneling attempt. The Southwest Tunnel and DRO-1 are located in the southern portion of the corridor, while the Belle Isle 10 foot diameter Intake Tunnel and the1874 attempt are located in the eastern area. The Southwest Land Tunnel and DRO-1 were built with tunnel boring machines or shields generally through soft to stiff clay soils. Air pressure was used during the DRO-1 construction. Toxic and explosive gases were encountered during the Southwest Land Tunnel construction. The Belle Isle 10-foot diameter Intake Tunnel was constructed under air pressure through soft clay. The 1874 tunneling effort was built by hand-mining techniques close to the soil/rock interface and encountered artesian groundwater infiltration from the bedrock into the tunnel bore. The groundwater carried hydrogen sulfide and produced a toxic atmosphere in the tunnel. Due to the groundwater and gas, the 1874 tunneling effort was abandoned.

3.3 Geotechnical Issues Related to Tunnel Construction

3.2.1. General

All elevations of geological strata are preliminary and approximate, although probably in the “right-order” and not likely to significantly affect the findings herein. The alignment and crossing location of any tunnel or bridge will depend on many factors, including the final selection of connecting roads and plazas.

3.2.2. Southern Section

Construction of a tunnel through the southern section using boring techniques within the soft ground profile would be difficult as the window for tunneling shrinks to approximately 7 to 13 m (20 to 40 feet) in places beneath the navigation channels. Given that the tunnel would need to be beneath the riverbed, the invert of any tunnel would be near or below the bedrock surface. Additionally, for any mined tunnel, adequate cover (typically 1 to 2 tunnel diameters, depending on conditions) between the river bottom and top of a tunnel is considered standard to reduce the risk of “daylighting” during boring. In areas where such cover is not possible, special design and construction considerations may allow for decreased cover, at increased cost and risk to the project. For the southern section, the available overburden would result in less than standard cover over the tunnel bore without mixed-face tunneling, where the major part of the tunnel face would be in rock. Such tunneling systems would involve high risk.

Construction of a bored tunnel through the dolomite bedrock is conceptually feasible. However, given the history of rock tunnels in the area, including the presence of hydrogen sulphide gas, possible artesian and karst conditions, a pressurized tunneling system such as slurry-face tunnel boring machines (TBM) and pre-cast gasketed concrete segments would be required.

It is envisioned that the TBM would be launched from open cuts on the river banks. Shaft construction for launching the tunneling operations and accessing the bored tunnel along the route would encounter gas and water and would require extensive rock grouting. Additionally, significant construction challenges could be expected in order to extend the tunnel through the soil-rock interface which would occur on each side of the river. Seismic reflection profiles taken by the U.S. Corps of Engineers indicate that significant boulders may be present above bedrock.

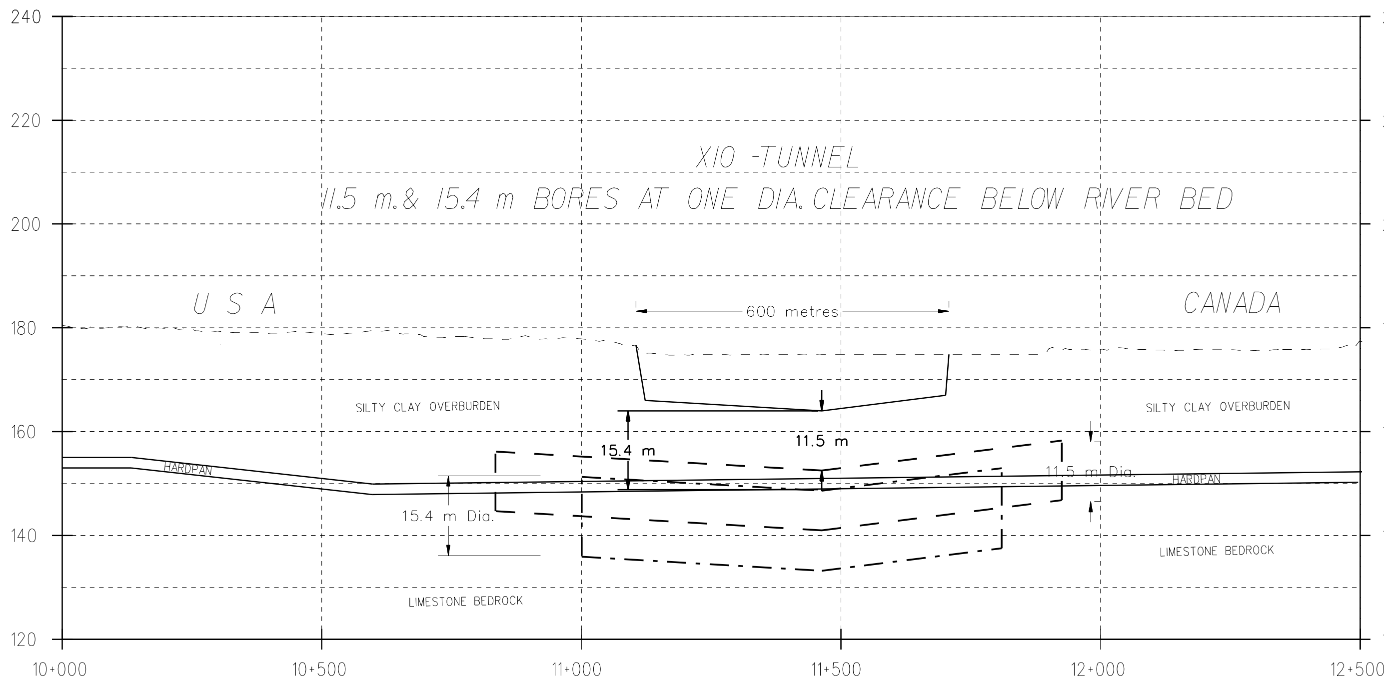
Cut-and-cover tunnels on the river banks would primarily be constructed through clay soils. In addition, this concept could potentially require some excavation into the hardpan and bedrock across the channel, which would be difficult. Environmental regulations regarding disturbance of river bottom sediments would preclude extending the cut & cover sections into the river. It is noted that for the CN Rail tunnel across the St. Clair River (about 60 km north), initial concepts for immersed tube tunneling were abandoned due to regulatory issues related to disturbance of sediments.

3.2.3. Central Section

Having developed the vertical profiles using the available topographical and geological data at the three potential crossing locations in the Central Section of the study corridor – X10, X11, and X14 (Figures 4 and 5), it is apparent that the thickness of overburden increases northwards. As discussed herein a soft ground bored two-lane highway tunnel tube must avoid the soil-rock interface where there can be both bedrock and boulders and must have sufficient cover of stiff glacial till to avoid river bed “daylighting” problems, such as those encountered on European river crossings. Seismic reflection profiles indicate a high potential for cobbles and boulders in the silty clay soil which would increase the risk of mixed-face tunneling. The profiles indicate that a two-lane 11.5 m external diameter soft ground tunnel within the silty clay would not be practically feasible at crossings X10 and X11 and X14 because the thickness of overburden above bedrock is insufficient to provide the necessary cover.

Figure #4

Tunnel Profiles - X10 & X11



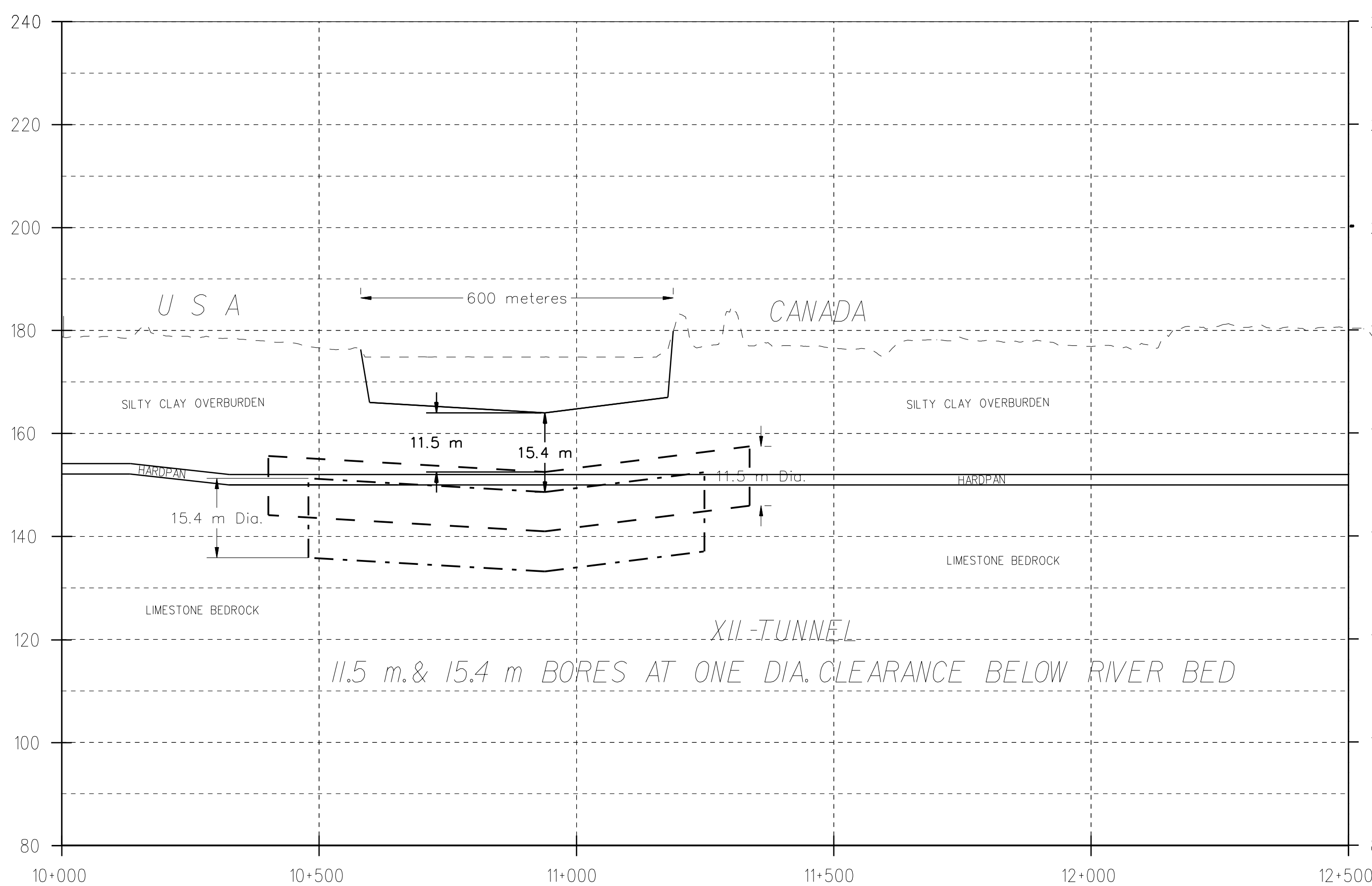
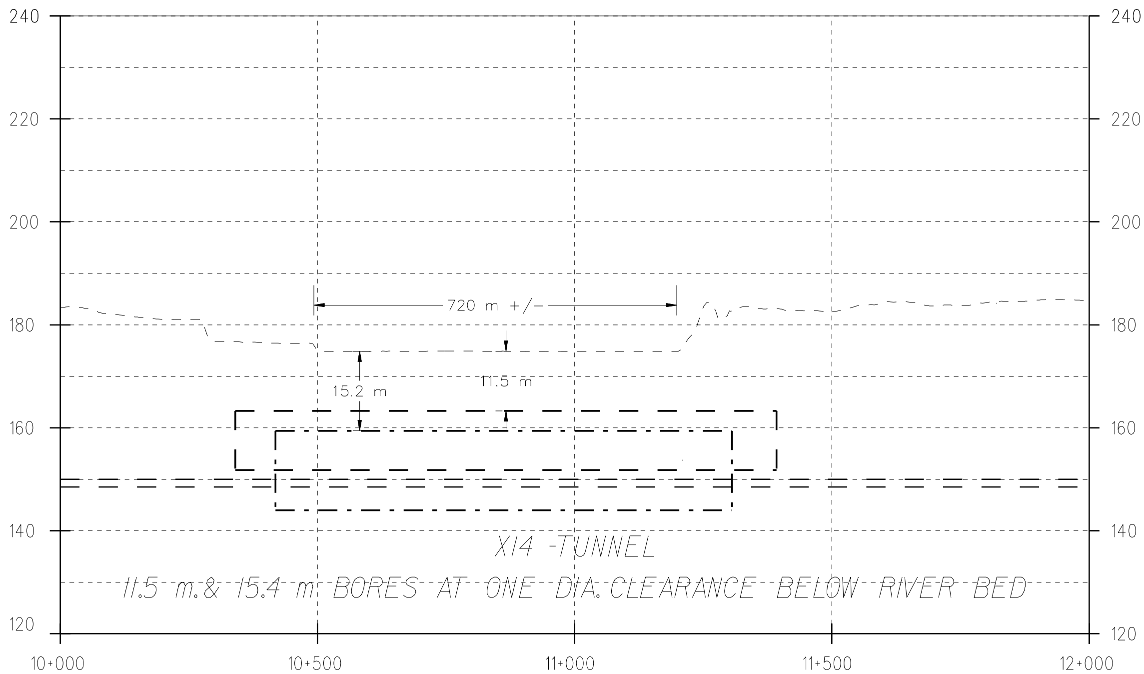
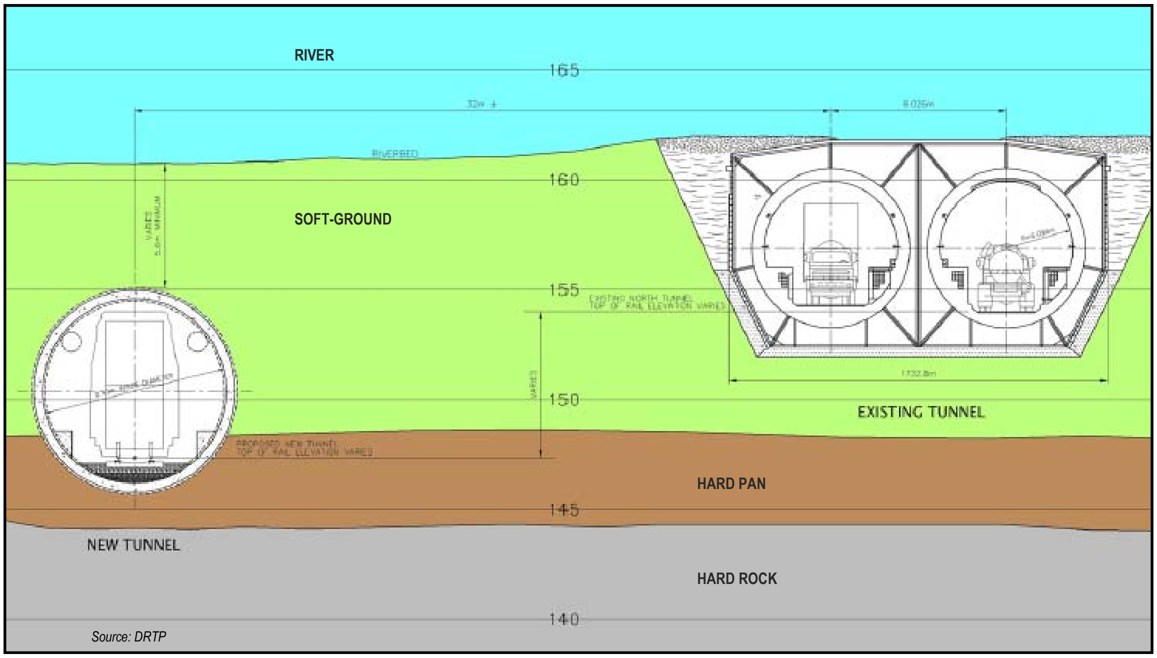


Figure #5
Tunnel Profiles - X14



Note should be taken that the profile showing the proposed rail tunnel at Crossing X13, shown below, indicates some 15 m thick clay layer over bedrock. This tunnel has a smaller diameter than the proposed 2-lane vehicular tunnel, discussed above, and would appear to be feasible although designs to eliminate risks associated with possible boulders as well as the presence of noxious gasses would need to be fully considered.



Detroit River Tunnel Partnership Cross Section

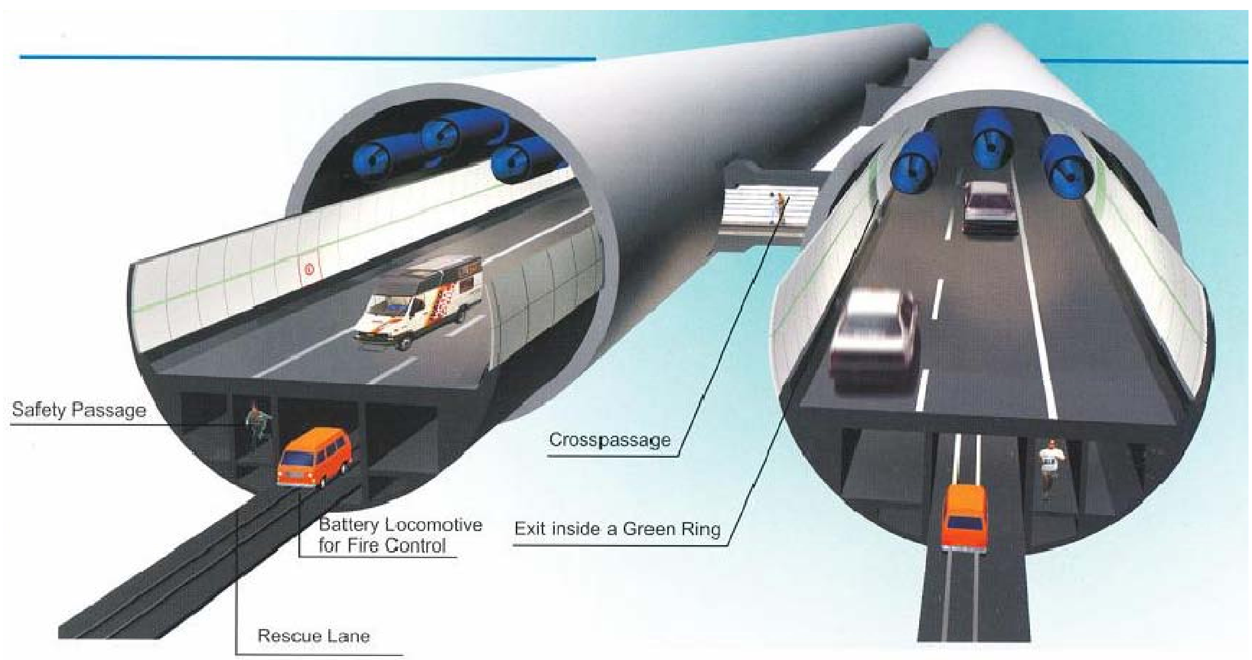
At X14, near the location of the proposed rail tunnel, having plotted the vertical profile using the available topographical and geological data at X15 (Figure 5), a proposed 11.5 m tunnel would have to avoid daylighting and buoyancy. Buoyancy occurs due to the presence of a high water table, and if there is thin cover over the tunnel, the buoyancy force may be greater than the resistance provided by the soil above the tunnel. Buoyancy can be mitigated by thickening the tunnel lining or placing a rock overburden on the river bottom, providing ballast under the roadway or a combination. These issues have been encountered in other locations, such the River Elbe tunnel. Placing sand and rock in the river bottom would have similar environmental impacts as cut-and-cover tunneling methods. Therefore, construction of a soft-ground TBM tunnel bore entirely through the silty clay soils at X14 is not practically feasible because the soft-ground envelope beneath the river navigation channel is inadequate.

Following are some of the issues relating to 11.5 m external diameter six-lane (two lanes per bore) and cut & cover tunnels:

- Risks due to potential presence of numerous large boulders;
- Potential problems in maintaining tunnel alignment;
- Requirement to grout rock in open cuts to minimize flow of noxious gasses;
- Possible presence of karst conditions;

- Environmental constraints to resolving driving difficulties by ground improvement from Detroit River;
- Requirement for state-of-the-art slurry TBM designed for the anticipated ground conditions;
- Possible risks associated with replacement of worn TBM cutters;
- Risks associated with construction of cross passages at 200 m (650 foot) intervals between bores to comply with National Fire Protection Association (NFPA) Standard 502; and
- Design of traffic management and fire safety systems to avoid traffic congestion in the tunnel.

Preliminary assessment of the fire and life-safety systems to assure road user safety indicates that it would be difficult to avoid congestion of traffic in the tunnel. Accordingly, semi-transverse or transverse ventilation would be required to comply with NFPA 502. A larger diameter tunnel would be required to provide sufficient headroom for heavy vehicles and space for the ventilation system, as shown below.



Consideration of the above issues indicates that a six-lane tunnel with three 11.5 m bores should be considered not practically feasible.

Although a 15.4 m (50.5 feet) TBM could be designed to comply with NFPA 502, with respect to fire and life safety, tunneling of two three-lane bores would require a deeper alignment to mitigate risk and would involve most of the issues listed above with respect to 11.5 m bored tunneling.

Rock tunnel construction in the Central Section of the DRIC Study corridor has a very poor history, with the last major rock tunnel being abandoned due to ground water and hydrogen sulfide gas infiltrations. Use of slurry face TBM's in the Limestone and Dolomite formations along with gasketed concrete segments would be required. The major impacts for a rock tunnel would be similar to those for the Southern Section, in addition to the generally poorer quality rock, with frequent voids and very permeable water bearing zones. Solution mining and salt mine concerns need to be addressed for either for mixed-face conditions or for rock tunneling beneath the river, similar to the Southern Section.

Cut-and-cover tunnel construction is not practically feasible in this section of the study corridor with similar issues raised for the Southern Section.

3.2.4. Eastern Section

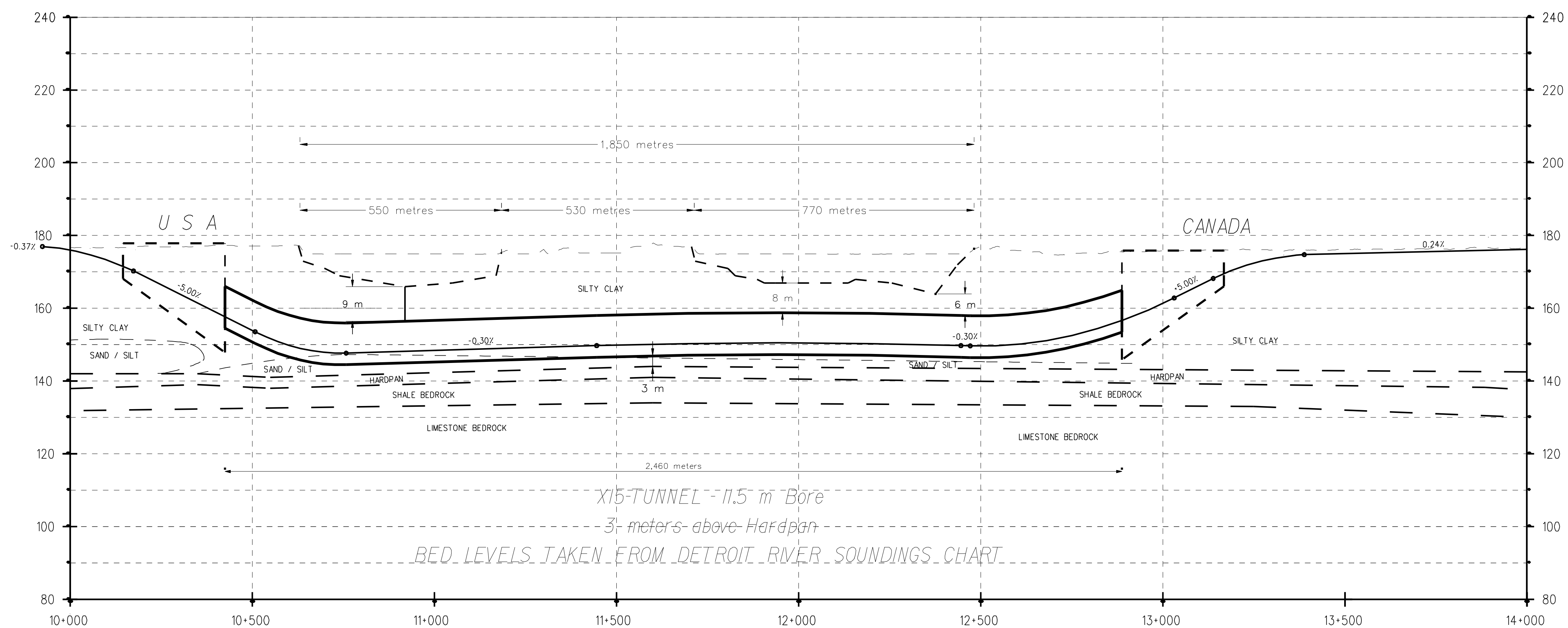
Having plotted the vertical profile using the available topographical and geological data at X15 (Figure 6) it is apparent that the thickness of overburden is not sufficient for either the two-lane or three-lane bores. At least 3 m (10 feet) of cover over the hardpan and/or bedrock would be recommended to facilitate steering the TBM above the irregular rock surface and/or boulders. Sufficient cover of stiff glacial till above the tunnel, to avoid river bed daylighting problems, such as those encountered on European river crossings, is also recommended. The three two-lane tunnel bores would not be practically feasible at this location, due to inadequate silty-clay envelope beneath the river bed (approximately 6 m (20 feet) of cover). It may be possible to reduce the cover requirement by designing a dense overlay to be placed over each tunnel bore on the river bed (to prevent tunnels' uplift due to buoyancy). This strategy, which involves considerable risk, is unlikely to be acceptable from environmental or river navigation viewpoints.

Even if the latter strategy were feasible, there would be significant risks associated with encountering large boulders in the glacial till as the TBM is steered close to the rock surface (to maximize cover) and in constructing cross-passages between tunnel bores for road-user escape in compliance with the NFPA Standard 502. Therefore, construction of a soft-ground TBM tunnel bore through the silty clay soils is not considered practically feasible.

Accordingly, conclusions regarding the feasibility of tunneling at this location are similar to those stated above with respect to the Central Section.

Rock tunneling, using previously-discussed methods, also is not practically feasible, due to the substantial risks as discussed above. Cut-and-cover tunneling within the overburden may also be feasible for this crossing within the overburden, with similar environmental issues as for the Southern Section. Solution mining issues appear to be less of a concern for the Eastern Section.

Figure #6
Tunnel Profile - X15



4. Environmental Considerations

4.1. River Sediments

Past sediment sampling has shown the presence of calcium, nickel, mercury, chromium, copper, zinc, cadmium, lead, arsenic, PCB's, DEHP, oils, and other contaminants within the sediments of the Detroit River. The chart below identifies is a listing used by the MDEQ to identify permit applications that may involve contaminated sediments on the Detroit River. Please note that the information below is a summary based on an initial data search by MDEQ and all areas of contamination may not be shown.

Town	Range	Sect	Comment
02S	11E	28	DEHP HG NI CU
02S	11E	28	PB PCB OIL ZN
02S	11E	29	DEHP HG NI CU
02S	11E	29	PB PCB OIL ZN
02S	11E	33	
02S	11E	33	DEHP ZN HG
02S	11E	33	NI CU
02S	11E	33	PB PCB OIL
02S	11E	34	DEHP HG NI CU
02S	11E	34	PB PCB OIL ZN
02S	11E	35	DEHP HG NI CU
02S	11E	35	PB PCB OIL ZN
04S	11E	5	AS HG CD CU
04S	11E	5	MONGUAGON CRK
04S	11E	5	PB ZN NI CR

Based on conversations with the MDEQ, contaminated sediments occur throughout the Detroit River but vary in concentration by location. Upstream of Belle Isle, the river is wide and water quality is generally good. Sediment contamination is primarily restricted to backwater depositional areas and near CSO outfalls.

Sediment contamination is generally found within depositional areas near the shoreline between Conner Creek and the Rouge River. PCB's concentrations are known to exist downstream of Connor Creek, and downstream of the Rouge River but again are mostly restricted to nearshore depositional areas.

Contamination is highest within sediments south of the Rouge River. These sediments are again believed to be concentrated in areas where deposition has occurred close to the shoreline. There are also areas of contamination where the Detroit WWTP discharges to the Detroit River, upstream of the Rouge River confluence. Construction of a submerged tunnel will likely result in disturbance of contaminated sediments within all three sections of the river. However, crossing within the Southern Section is expected to result in greater impacts due to higher contaminant concentrations in that area. Regulatory agencies will require sediment testing if any of the bottom sediments within the river will be dredged. Test results will determine if such a construction methodology would be permitted, and if so, what restrictions will be imposed on the methods of dredging and disposal location of dredged sediments.

4.2. Shoreline and Inland Conditions

The upper Detroit River consists of a single, well-defined channel about 700 meters to 1,000 meters wide. A number of islands divide the lower river into distinct channels, which have been dredged for navigational purposes. Limited natural wetland areas remain along the Canadian portion of the lower river. Nearly all of the shoreline on the US side of the river has been artificially hardened (sheet pile and concrete).

The majority of the project area inland from the river is developed with a variety of land uses (industrial, commercial, residential, etc.). However, limited vacant land is still present in the western portions of the Southern Section.

The Michigan Department of Environmental Quality has funded a number of projects along the shoreline of the Detroit River. These projects were funded under Coastal Zone Management (CZM) monies and include projects designed for public access, resource management, and public benefit in general. The table below identifies some of the larger and more recent projects and their approximate location along the river.

The majority of recent projects are located within the Southern and Eastern Sections. A crossing within these sections has a greater possibility of impacting CZM projects. Impacts to CZM projects do not appear to be dependent on the method of crossing.

Year	Name	$ CZM Amount	Description of Work
EAST SECTION			
2005	Belle Isle Nature Center	50K	Nature Trail on SE portion of island. Belle Isle is the most heavily used Detroit Park.
1998	Lakewoood East Park	50K	Repair promenade and do engineering and design to upgrade
1998	Belle Isle Nature Center	30K	Educational interpretive exhibits.
2002	U of M Sea Grant	300K	Develop 3 sturgeon spawning reefs off Belle Isle and monitor
2002	Blue Lagoon	250K	Habitat inventory and restoration of 9 acres of wetland habitat including prairie.
CENTRAL SECTION			
2002	Historic Fort Wayne	23K	Evaluate stabilization and maintenance requirements for the site
SOUTHERN SECTION			
1997	Linked Riverfront Project	10K	Prepare master plan to develop linkage of riverfront parks in Trenton

Year	Name	$ CZM Amount	Description of Work
2001	Grosse Ile	47K	Thoroughfare canal scenic overlook and boardwalk
2001	Trenton	34K	Linked riverfront park connectors study and repairs to connector elements
2002	Elizabeth Park	50K	Stabilize shoreline and develop wetland and expand shoreline walkways.
2002	Greenways Trails	10K	Evaluate trail system from Lake Erie Metropark to Elizabeth Park in Trenton.
2004	Ecorse	45K	Frenchman's Cove analysis of land use to identify redevelopment opportunities on the riverfront
2004	Trenton	50K	Detroit River International Wildlife Refuge- Develop comprehensive management plan
2005	Ecorse	31K	Shoreline improvements, design for shoreline walkway, public access, and boardwalk
POTENTIALLY ALL 3 SECTIONS			
1997	Rails to Trails	23K	Master plan for greenway including 6 miles of Detroit River frontage.

4.3. Permitting Agencies and Requirements

Permits and/or approvals that are associated with resource protection will be required for construction of a tunnel from the following agencies:

- Michigan Department of Environmental Quality (MDEQ), Land and Water Management Division (LWMD) for wetlands, CZM Consistency, floodplains, and inland lakes and streams (Detroit River, Rouge River, Connor Creek, etc.), under Parts 303, 301, and 31 of the Natural Resource and Environmental Protection Act (NREPA), 1994 PA451, as amended

- U.S. Army Corps of Engineers (USACE), Regulatory Branch for wetlands, floodplains, and inland lakes and streams (Detroit River, Rouge River, Connor Creek, etc.), under Section 10 of the Rivers and Harbors Act and Section 404 of the Clean Water Act

- Michigan Department of Environmental Quality, Water Bureau for water quality certification, and discharge to surface waters (NPDES and Stormwater)

- Wayne County Department of the Environment (potentially)

- US Fish and Wildlife Service (USFWS) for impact to Federally listed T&E species

- MDEQ Waste and Hazardous Materials for contaminated sediments

- Michigan Department of Natural Resources, (MDNR), Wildlife Division for impacts to T&E species

Each permit process requires submittal of information as set forth in the regulating statutes. Permit review criteria are also set forth in the statutes and are, in some case extensive and detailed. However, generally speaking, permits associated with construction within the Detroit River will be reviewed for impacts to water quality, sediments, and fish and wildlife habitats. It is the applicant's responsibility to show that no feasible and prudent alternative is available that has less impact on the aquatic resources.

Based on experience with the MDEQ and the USACE, permits will be difficult to obtain for construction of a sunken tunnel when other methods are available that minimize or eliminate disruption of sediments and habitats.

Permits from the MDEQ and USACE will be denied or withheld if commenting agencies (MDNR Wildlife Division, MDNR Fisheries Division, Environmental Protection Agency, USFWS, etc.) object to the permit. Consultation with regulatory agencies is recommended to provide direction when considering resource impacts and permittability of the method and location of the crossing. At a minimum, agency feedback would be sought for:

- Specific location of known contaminants, testing requirements, dredge disposal requirements (MDEQ, USACE)
- Known ecological areas and habitats (MDEQ, MDNR Wildlife, MDNR Fisheries, USFWS, EPA, Wayne County Department of the Environment)
- Mitigation requirements for impacts to wetlands, floodplains, surface waters, sediments, and T&E species (MDEQ, MDNR, USACE, USFWS)
- Survey requirements for T&E plant and animal species (MDNR, USFWS)
- Preliminary impressions of project permittability and acceptable resource impacts for tunnel methods and locations, given known values and locations of the aquatic resources (MDEQ, MDNR, USACE).

5. Summary

5.1. Impacts and Benefits

Each tunnel type has associated benefits and impacts. Generally speaking, tunnels provide a means of crossing that has little visual impact and can be employed to avoid long-term impact to sensitive areas. However, tunnels do have associated construction impacts that may overcome such benefits. The following table summarizes, by tunnel type, the impacts and benefits.

Tunnel Type	Impacts	Benefits

Tunnel Type	Impacts	Benefits
Rock	Difficult tunneling, karst, noxious gasses, blasting in urban areas, ventilation systems, traffic management systems.	Tunnels avoid some above ground impacts of physical infrastructure and truck and auto traffic.
Bored Soft Ground	Difficult tunneling, limited soil cover, noxious gasses, tunnel size limit, ventilation systems, traffic management systems.	Tunnels avoid some above ground impacts of physical infrastructure and truck and auto traffic.
Submerged	River bottom disturbance during construction, ventilation systems, traffic management systems.	Relatively short design-construct period, flexibility in design of tunnel cross section

5.2. Summary Matrix

The following matrix summarizes the practical feasibility of tunnel types by geographic location:

Category	River Section		
	Southern	**Central**	**Eastern**
Geotechnical Conditions			
Soil Cover – River Bottom to Top of Rock (m)	7 to 8	15	18 to 25
Depth to Rock from surface (m)	17 to 20	24 to 28	40 to 45
Evaluation			
2-Lane Bored Tunnel	**Not Feasible** • Insufficient soil depth	**Not Practically Feasible** • High risk & cost • Environmental Issues	**Not Practically Feasible** • High risk & cost • Environmental Issues
3-Lane Bored Tunnel	**Not Feasible** • Insufficient soil depth	**Not Practically Feasible** • High risk & cost	**Not Practically Feasible** • High risk & cost
Rock Tunnel (4 lane)	**Not Practically Feasible** • Poor rock • Deep tunnel/ long approaches • Poor history	**Not Practically Feasible** • Poor rock • Even deeper tunnel/ long approaches • Poor history	**Not Practically Feasible** • Poor rock • Very deep tunnel/ long approaches
Rock Tunnel (6 lane)	**Not Practically Feasible** • Poor rock	**Not Practically Feasible** • Poor rock	**Not Practically Feasible** • Poor rock
Submerged Tunnel (4 lane)	**Not Feasible** • Rock excavation required • Environmental Issues	**Technically Feasible** • Engineering **Not Practically Feasible** • Environmental Reasons	**Technically Feasible** • Engineering **Not Practically Feasible** • Environmental Reasons

	River Section		
Submerged Tunnel (6 lane)	**Not Feasible** • Rock excavation required • Environmental Issues	**Technically Feasible** • Engineering **Not Practically Feasible** • Environmental Reasons	**Technically Feasible** • Engineering **Not Practically Feasible** • Environmental Reasons

In summary, it is not considered practically feasible on the basis of available data to attempt construction of a highway tunnel under the Detroit River in the DRIC Study corridor.

The conclusions expressed herein are based on preliminary and approximate geological data, which would need to be checked in the field in order to verify the impacts related to tunnel boring predicted herein.

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