CITY COUNCIL Agenda Item #18-103
Date: March 28, 2018
Consent ___ Discussion _X_

SUBJECT: Flood Mitigation Study update

SUBMITTING DEPARTMENT: City Manager's Office

RECOMMENDED ACTION: Receive presentation from Jeff Tucker and Dave Conger of Dubois & King on the Winooski River Flood Damage Risk Mitigation Study.

RELATED COUNCIL GOAL/PRIOR ACTION:

C: Public Safety
E: Housing
F: Quality of Life

EXPENDITURE REQUIRED: None at this time

SOURCE OF FUNDS: N/A

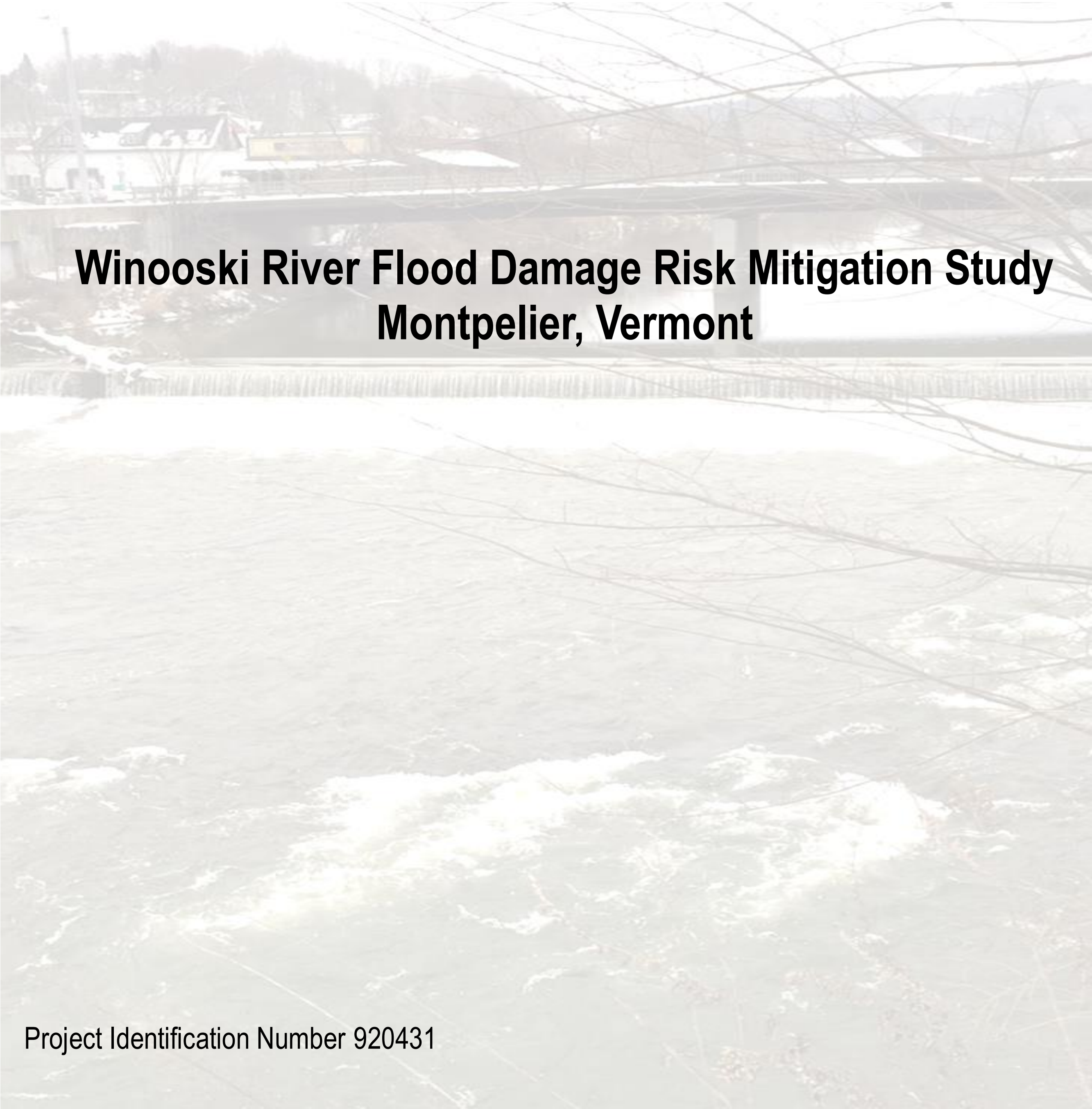
LEGAL REQUIREMENTS: None at this time.

BACKGROUND INFORMATION: DuBois & King, the US Army Corps of Engineers and the State of Vermont are working together on a Winooski River Flood Damage Risk Mitigation Study. This project was initiated after ice jam concerns in the late 2000's. Funding has been provided by the Army Corps of Engineers (50%), State of Vermont (25%) and the City of Montpelier (25%). This is an opportunity to review and comment on the draft report. The next step will be to meet with State and Corps officials prior to finalizing. City, State and Corps will have to decide whether to move forward with a recommended project.

SUPPORTING DOCUMENTS: City Review Draft of the Winooski River Flood Damage Risk Mitigation Study.

INTERESTED PARTIES: City Council, Residents

CITY MANAGER'S APPROVAL:



Winooski River Flood Damage Risk Mitigation Study
Montpelier, Vermont

Project Identification Number 920431

DuBois & King inc.

CITY REVIEW DRAFT

US Army Corps of Engineers®
New York District

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1.0 Introduction

Montpelier, Vermont is the state capital and a regionally important center of commerce. Although the resident population is less than 8,000, the daytime population is around 21,000 (Crane Associates, 2005). The first settlement was in 1787 and by the mid-1800s is was a center of manufacturing powered by mills along the Winooski River. Today, state government and the insurance industry are the primary economic drivers. In terms of flood inundation potential, Montpelier is in an area of very high risk. Despite flood control dams in Winooski River tributaries, the city has a long history of devastating flood damage. Nestled in a valley surrounded by steep hills, and with extensive commercial development within the floodplain, Montpelier is at risk for substantial economic damages due to flooding, particularly ice jam induced flooding. In 1992, for example, an ice jam on the Winooski River in Montpelier caused floodplain inundation of over five feet within one hour. Fortunately, it occurred during the day and there were no fatalities, but it resulted in an estimated $5,000,000 in damages. Understanding how, where, when and why ice jams occur in the Winooski River at Montpelier, and planning for the desired future conditions that mitigate the flooding risk, is crucial for Montpelier, the State of Vermont, and the nation. Consequently, the U.S. Army Corps of Engineers, New York District, was authorized to conduct a feasibility study on flood risk mitigation for Montpelier, Vermont. This report documents the feasibility study, a cooperative effort between Dubois & King, The U.S. Army Corps of Engineers, the State of Vermont, and the City of Montpelier.

1.1 Authority

The feasibility study for the Winooski River in Montpelier, VT was initiated under the authority of Section 309(i) of the Water Resources Development act of 1992.

1.2 Study Purpose

The purpose of the feasibility study is to determine whether a cost-effective federal project is capable of mitigating some of the risks associated with ice jam induced flooding, and to document the design concept and cost-benefit analysis proposed to achieve the flood risk reduction. To accomplish this, previous reconnaissance information and feasibility studies were reviewed, and a numerical model simulating floodplain inundation extent, depth and damage was calibrated to historical stream measurements. This numerical model was used to estimate the flood inundation and damage characteristics of both existing conditions and proposed future conditions. Limitations of model-simulated estimates of flood inundation and damage characteristics are described.

2.0 Background

The study area is located in the City of Montpelier, Washington County, Vermont (Figure 1). Montpelier is the state capital of Vermont and had a population of 7,855 in the 2010 census (U.S. Census Bureau, 2016). The study area includes the Winooski River and three of its tributaries: the Dog River, North Branch, and Stevens Branch (Figure 2). Specifically, the study area limits include the 0.2 percent annual exceedance probability (500-year) floodplain of the Winooski River from the City of Montpelier/Town of Middlesex town line upstream 5.5 miles to the City of Montpelier/Town of Berlin line, 0.5 miles up the Dog River, 0.7 miles up the North Branch, and 0.5 miles up the Stevens Branch.

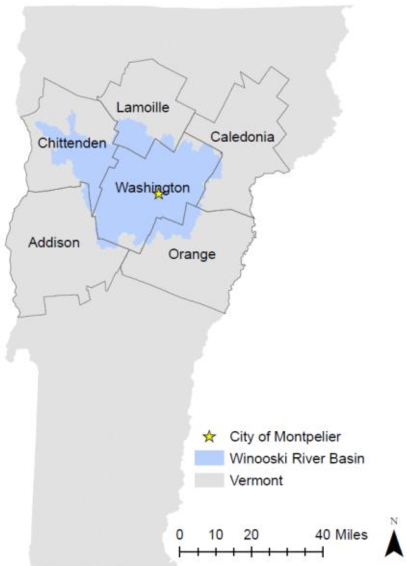

Figure 1. Location of Winooski River Basin, central Vermont.

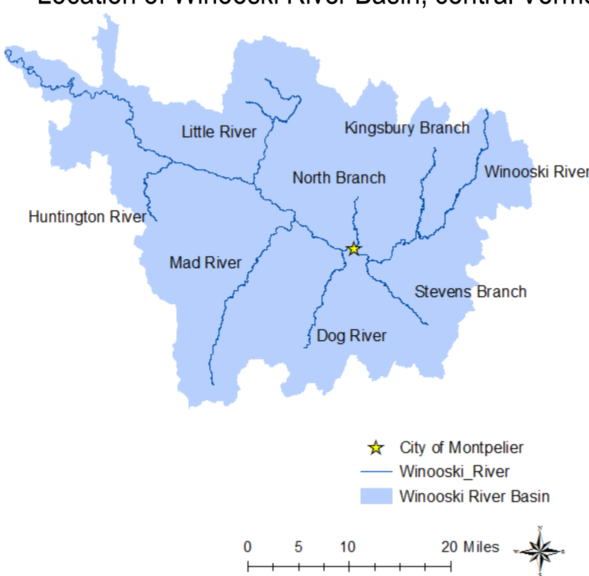

Figure 2. Location of Winooski River Basin, central Vermont.

The floodplain inundation and damage assessment numerical model domain (Table 1) includes 11 miles of streams/rivers and 595 structures in the floodplain. The total drainage area of the Winooski River is 1,060 square miles (11 percent of the State of Vermont). The total drainage area is 193 square miles at the upstream limit (Montpelier city limits border with the Town of East Montpelier) and 519 square miles at the downstream limit (Middlesex Dam 2). Drainage areas and other watershed characteristics of the Winooski River and the three noted tributaries are shown in Table 1.

Table 1. Winooski River, Dog River, North Branch, and Stevens Branch watershed characteristics.
[Drainage Area in square miles; percent waterbodies and wetlands determined from the National Land Cover Dataset from 2006; Mean annual precipitation in inches for 1981 to 2010 from PRISM; Percent of developed land from the National Land Cover Dataset 2011 classes 21-24]

Stream/River	Area	Percent waterbodies and wetlands	Mean annual precipitation	Percent of developed land
Winooski River	1,060	2.24	45.6	7.7
Winooski River at city limits	193	3.46	42.4	4.98
Winooski River at Middlesex Dam 2	519	2.19	43.1	6.82
Dog River	93.1	0.96	44.3	5.43
North Branch	77.8	1.38	47	3.4
Stevens Branch	115	2.01	41.5	12.5

2.1 History of Flooding in the Basin

Much of the City of Montpelier commercial and government area lies within the floodplain of the Winooski River or one if its tributaries. Fluvial and ice jam-induced floods in the city have caused periodic loss of life and economic damage for over 200 years. DuBois & King (1996) includes a comprehensive chronology of historical storms and flooding in Montpelier, Vermont. The risks from fluvial flooding are reasonably well understood in comparison with ice jam-induced floods. Additionally, it is complex to estimate the return period for a flood caused by an ice jam because the river discharge may not be correlated with inundation magnitude or depth, and the physics of an ice jam is site- and condition-specific.

In general, ice jams that occur in the project area are associated with breakup during a mid- to late-winter thaw. Typically, ice cover in the steeper sections of the Winooski River, Dog River, Stevens Branch, or North Branch will break up and run downstream during or shortly after periods of warm temperature and rainfall. Broken ice can lodge against a more stable cover of ice located in the main stem, or against constrictions such as river bends or bridge piers. The energy available to pass this unstable ice through Montpelier is constrained by the reduction in the energy gradient caused by the decrease in river channel slope, numerous structures in the river, and backwater conditions downstream.

2.2 History of Corps Involvement

Prior to the initiation of the feasibility study, the U.S. Army Corps of Engineers performed an initial reconnaissance study of the flooding problems in Montpelier (DuBois & King, 1996). This study was completed in 1994 and revised in 1996. It found sufficient Federal interest for flood damage reduction to pursue a feasibility study.

3.0 Planning Needs, Opportunities, Constraints, and Objectives

3.1 Current Needs

The current need is to develop a long-term solution to reduce the flood damages that result when the Winooski River reaches and/or exceeds flood stage due to an ice jam event.

3.1 Planning Opportunities

The planning opportunities identified include reducing the flooding in the city of Montpelier; reducing emergency costs in responding to flooding events; and contributing to the national economy by reducing repair, rehabilitation and flood fighting costs associated with flood damage to structures and supporting infrastructure.

3.2 Planning Constraints

Planning constraints include technical, environmental, cultural, economic, regional, social and institutional considerations that act as impediments to successful achievement of the planning objectives of possible solutions.

Technical Constraints

- Plans must be realistic and utilize existing technologies;
- Plans must represent sound, safe, acceptable engineering solutions;
- Plans must be in compliance with Corps of Engineers' Engineering Regulations;
- Plans must tie off into stable high ground to ensure that they are not flanked by flood waters, and that they do not fail from behind.

Environmental Constraints

- Plans cannot unreasonably impact environmental resources;
- Plans must consider mitigation or replacement where a substantial impact is established, and should adopt such measures, if justified.

Cultural Constraints

- Plans must consider impacts to cultural and historic areas.

Economic Constraints

- Plans must be justifiable; that is, plan benefits must exceed plan costs (there must be net excess benefits);
- Plans must be efficient; they must represent near optimal use of resources in an overall sense. Accomplishment of one economic purpose cannot unreasonably impact another economic system.

Regional and Social Constraints

- The needs of the region must be considered and one area cannot be favored to the unacceptable detriment of another;
- No favoritism can be shown; all reasonable opportunities for development within the study scope must be weighed, one against the other.

Institutional Constraints

- Plans must be consistent with existing Federal, state, and local laws;
- Plans cannot be adopted that would benefit a single user to an unreasonable degree;
- Plans must be fair and find overall support in the region.

3.3 Planning Objectives

Planning objectives were identified based on the problems, needs and opportunities, as well as on existing physical and environmental constraints present in the study area. In general, the prime Federal objective is to contribute to National Economic Development (NED) consistent with protecting the nation's environment, pursuant to national environmental statutes, applicable executive orders and other Federal planning requirements. Accordingly, the following objectives were identified:

- Decrease the threat to public health and safety and limit interruption of vital services from flooding and streambank erosion;
- Increase NED benefits in all plan components, in accordance with the limits of institutional participation; and,
- Where possible, implement the environmental operating principles of the U.S. Army Corps of Engineers.

3.4 Design Criteria

The design criteria being used to develop the alternatives include the following:

- No substantial increase in interior drainage problems;
- Reduce the probability of ice jam formation;
- Limit environmental impacts;
- Increase the level of protection;
- Reduce flood damage due to ice jam formation; and
- Utilize proven technology.

3.5 Economic Criteria

The alternatives or combination of alternatives will be analyzed to determine the National Economic Development (NED) plan. This plan will optimize the relationship between the costs of any potential project versus any possible benefits resulting from the project. The benefits will consist primarily of a reduction of flood damages and avoidance of emergency costs.

4.0 Existing Conditions of Project Area

The geology of the study area is characterized by narrow valley floors ranging from 500-1,500 feet, with steep hillside slopes extending 500 feet above the Winooski River. Consequently, flash floods are possible year-round. The relief also causes fast releases of river ice during break up, resulting in nearly instantaneous ice jams and subsequent floodplain inundation. The physiographical location is defined as the New England Uplands (Fenneman, 1938). Tectonically, the study area is located in the Crystalline Appalachians Province (King, 1959).

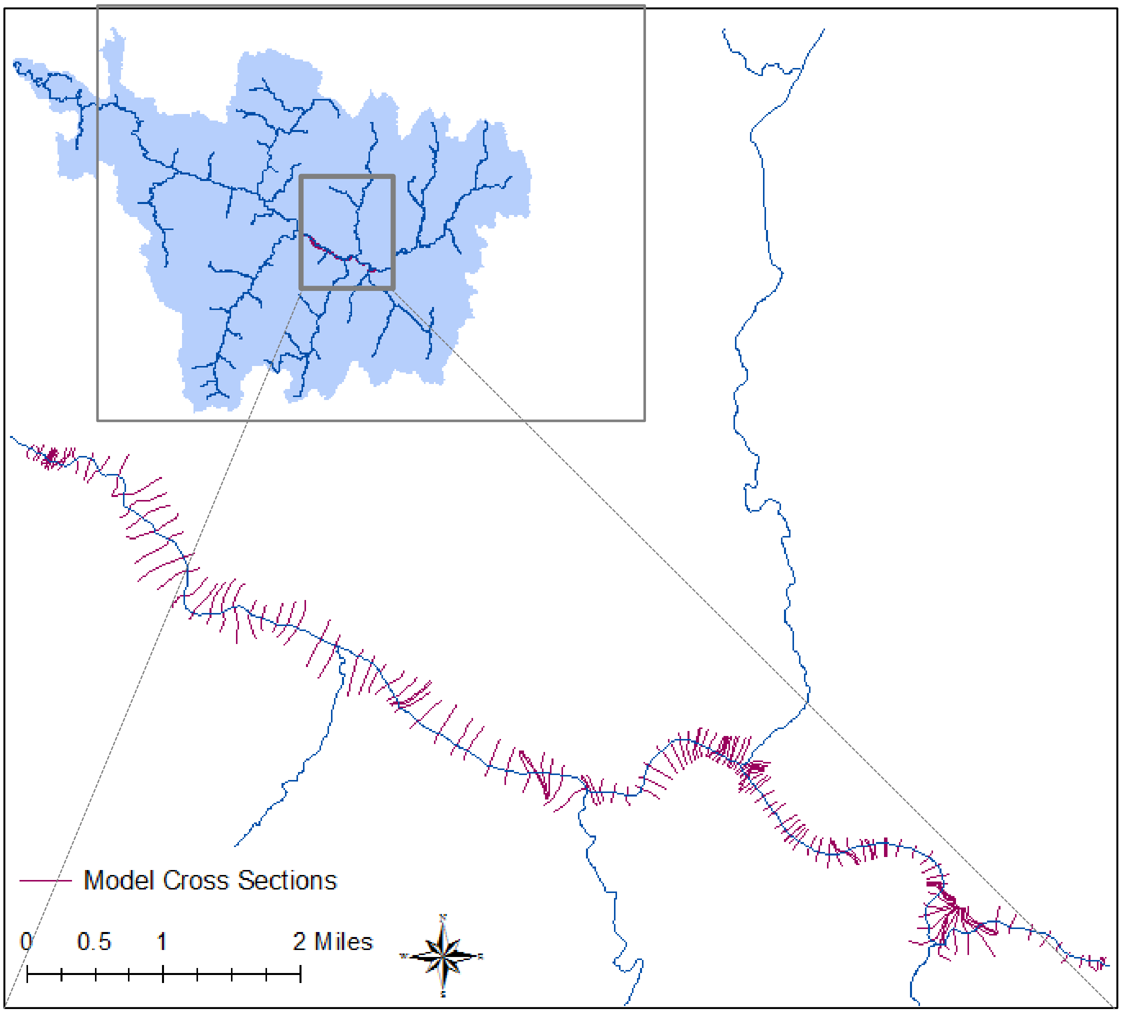

Figure 3. Numerical model domain of the Winooski River and tributaries, central Vermont.

Soils in the region vary in depth, covering deltas, deposits of gravel, sand, and clays. The upland material is predominantly glacial till and the valley floor consists of glacial deposits, sediments, and alluvial soils. The river bed consists of rock outcrops and alluvial deposits of gravels and sands. Silt accumulations are found behind dams and naturally slow-flowing regions. Mean annual precipitation is approximately 43 inches. Precipitation generally occurs as low intensity long duration transcontinental storms, while higher intensity, shorter duration coastal and hurricane storms occur infrequently.

5.0 Plan Formulation

The Dubois and King (1996) reconnaissance study recommended investigating the feasibility of a single set of ice retention piers with a bypass channel on the Winooski River, construction of floodwalls along portions of the North Branch and Winooski River, a combination of a single set of ice retention piers with a bypass channel on the Winooski and construction of floodwalls along portions of the North Branch and Winooski River, and a dual set of ice retention piers on the Winooski River. Since the reconnaissance study, and in consultation with project partners, one additional approach was considered (using mechanical and/or thermal weakening/breaking), and one approach was eliminated because of the cost (building new floodwalls along the North Branch and Winooski River to sufficiently protect downtown Montpelier).

5.1 Expected Future Conditions without Project

Without the project, the City of Montpelier will have real-time monitoring of river stage linked to an automated warning system that notifies appropriate individuals at pre-defined river stages. Future damages without the project are expected to average $431,275 per year.

5.2 Flood Mitigation Alternatives

Consequently, the feasibility plan formulation included four alternatives:

1. Single ice retention structure upstream of Granite Street with a bypass channel
2. Two ice retention structures (upstream of Granite Street and near Main Street) with a single bypass channel upstream of Granite Street
3. Mechanical and/or thermal weakening/breaking (no structures)
4. No Action

Since the 1992 event, the City of Montpelier has implemented aspects of mechanical and thermal weakening and ice breaking. However, this is not something that can be modeled readily, and its effect on the occurrence of large ice jams is uncertain at this point. Breaking the ice cover in key areas in advance of natural breakup has been an effective ice jam mitigation strategy on many ice jam prone rivers in Canada. A program of timely ice breaking in the Cemetery Bend section of the Winooski is therefore worthy of consideration as a means of preventing a 1992-like ice jam and flood.

Ice control structure locations evaluated are shown in Figure 4. The downstream location is the same for all ice control structure scenarios. The upstream ice control structure location changes for each evaluation.

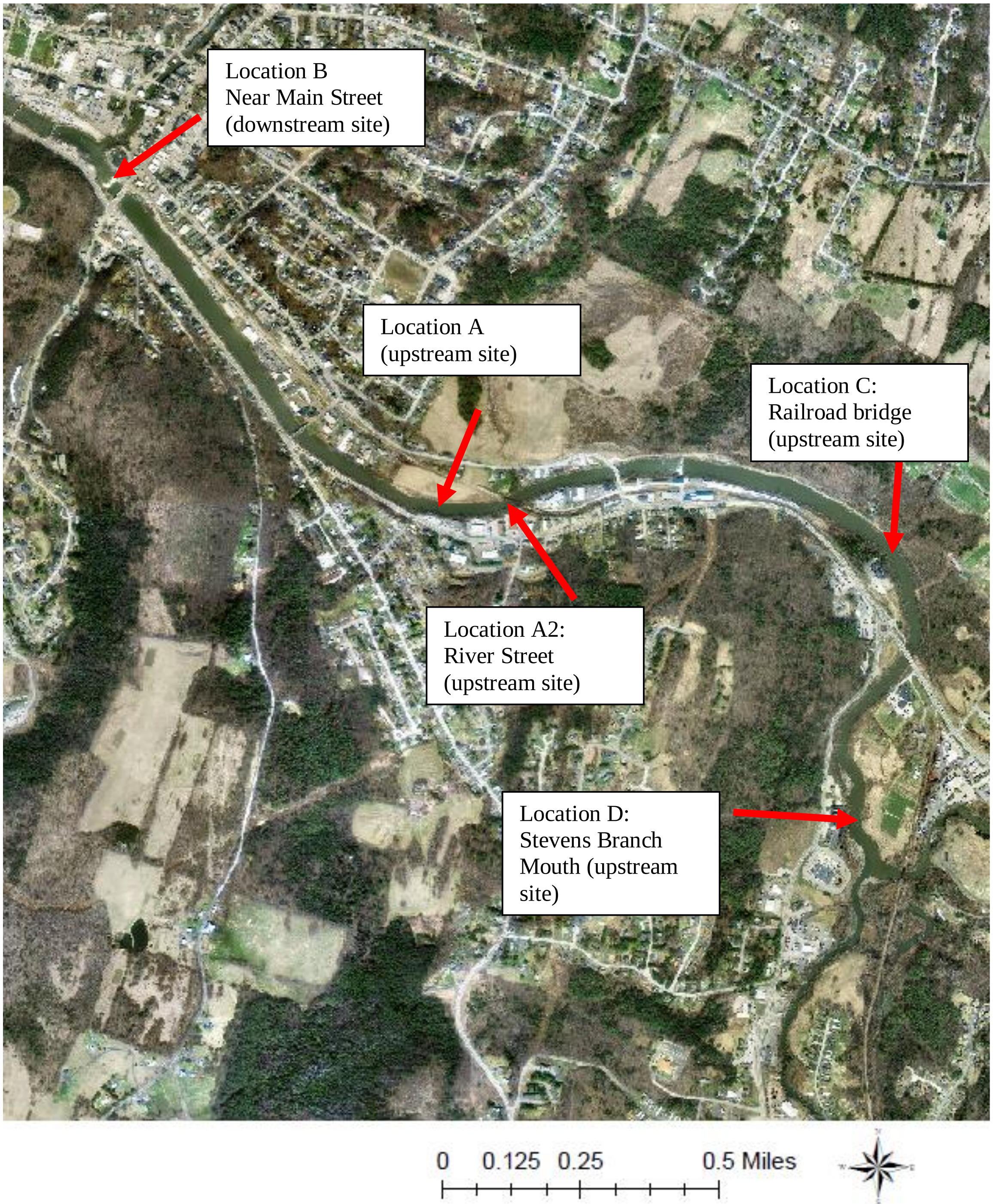

Figure 4. Aerial photo of Montpelier and the locations where ice control structures were evaluated.

5.3 Evaluation of Alternatives

5.3.1 Alternative 1: Single Ice Control Structure with Bypass

- Consists of ice piers with bypass channel:
  1. Keeps ice together, prevents passage downstream
  2. Bypass provides relief until the jam deteriorates in place
  3. Close enough to downtown to retain an adequate volume of ice

Based on the numerical modeling effort, this alternative has the greatest benefit to cost ratio of all of the alternatives. However, numerical models are only tools, and engineering judgement from multiple ice engineering experts consulted throughout the duration of this project concluded that the second ice control structure in Alternative 2 was important for protecting the State Street area and the area along the North Branch. The first ice control structure includes a bypass channel and is the more expensive of the two ice control structures.

Without a bypass channel capable of conveying several thousand cubic feet per second of streamflow (average daily flow was 4,700 cfs during the March 11, 1992 ice jam flood), the effectiveness of any arrangement of ice control structures is uncertain. The bypass channel allows water to flow around the jam at the piers and continue downstream. Without this bypass flow, upstream stage will increase, possibly causing induced flooding, until the jam releases and the ice moves downstream. An ice retention structure without an adequately-sized bypass channel may create more flood damage than it prevents. Due to channelization and past development along the river, there remain few locations close enough to the city suitable for an adequately-sized bypass channel without purchasing several lots, doing extensive excavation, and/or moving roadways.

Provided the ice control structure reliably retains the ice run, the benefit to cost ratio for the one structure alternative, with the upstream ice control structure at the distillery site, is 2.12:1, which indicates that the benefits of the project, in terms of damage reduction, outweigh the expected damages without the project over a 50-year project life. This ratio provides a guidepost, but should not be the primary factor in the determination of the most appropriate alternative.

Advantages: Highest modeled benefit-to-cost ratio, proven technology, minimal operational requirements with a passive system.

Disadvantages: Potential to induce flooding upstream of the structure, debris jam potential, ecosystem impact of the structure.

5.3.2 Alternative 2: Two Ice Control Structures

- Includes everything noted in Alternative 1
- Second structure is piers only (no bypass channel), located near the Main Street Bridge
- Captures ice created between the upstream ice control structure and the second ice control structure

This alternative, like the first alternative, was simulated using a hydraulic model and a financial model. The benefit to cost ratio for the alternative was 1.69:1, indicating that the expected flood damage reduction with the project in addition to the cost of the project exceed the expected flood damage without the project. The model-generated benefit to cost ratio is lower than for the alternative with only one ice control structure, however, multiple ice engineering experts, from government and industry, recognize this alternative as the one most likely to result in the desired outcome of cost-effectively minimizing damages in downtown Montpelier. However, the benefits to downtown Montpelier come at the expense of structures upstream of North Branch confluence with the Winooski River. Two concerns with no bypass channel are that ice accumulation behind the piers could raise water levels enough to flood upstream areas, and the stage could increase to the point where the retained ice releases. Neither of these conditions are straight-forward to model.

Advantages: Modeled benefit to cost ratio greater than one, proven technology, minimal operational requirements with a passive system.

Disadvantages: Potential to induce flooding upstream of both structures-particularly along Stone Cutters Way, debris jam potential, ecosystem impact of the structures, without a bypass channel downstream the hydraulics during an event are currently unknown.

5.3.3 Alternative 3: Mechanical/Thermal Weakening and Removal

- Techniques
  - Cutting ice into strips and allowing standing water to melt ice
  - Amphibex or similar (amphibious excavator) smashes ice into relatively small pieces
    - On years with thick late winter ice, break up ice cover in Cemetery Bend from Bailey Avenue Bridge to ledges downstream of the gage in advance of natural breakup. In a 1992 breakup scenario, had the Cemetery Bend ice been pre-broken, the breakup wave might have progressed through this section avoiding the historic jam. Decision and timing of ice breaking would need to be determined from close monitoring of ice and weather conditions leading up to breakup. This combination of monitoring and ice breaking is an effective means of ice jam mitigation at many sites in Canada.
  - Usage of a crane with a steal I-beam to destroy the cover upstream of the I-89 Bridge
  - Use of excavator with long boom
  - Thermal techniques in advance of breakup, such as dusting the ice cover and routing warm effluent from the Montpelier wastewater treatment plant to melt ice in the Cemetery Bend area.

Advantages: Minimal ecosystem impact, low cost, city can take pro-active actions ahead of an anticipated event, minimal recreational impact.

Disadvantages: Large area to apply technique, must be timed correctly and complete prior to break up, limited thermal energy from wastewater plan effluent available resulting in minimal impact in thick ice, high operational cost, untested effectiveness.

This alternative has the advantage of not building a permanent structure in the river. Any structure in the river has the potential to cause flooding where it would not have occurred otherwise. There may be other unintended consequences of having a permanent structure in the river, such as detracting from the natural beauty of the river, limiting certain recreational activities, or affecting the aquatic ecosystem. Also, pier structures may retain woody debris requiring periodic debris removal. Examples of similar structures that likely have similar maintenance requirements include the pier structures on Oil Creek in Pennsylvania and Cazenovia Creek near Buffalo, New York. During a heavy rain event shortly after the Cazenovia Creek ice control structure was built, enough woody debris was retained at the piers to block the main channel and divert most of the river flow out of bank and around the structure. The rock armor along the berm and bank was substantially damaged where flow exited and re-entered the channel. Before piers are installed in the river, the debris load on the Winooski River through Montpelier would need to be defined and mitigated. Finally, the structure may fail to produce the desired benefits. For all of these reasons, this non-structural alternative may be attractive. The effectiveness science, technology, and application of mechanical/thermal weakening and removal is lacking when an ice jam occurs unexpectedly. The benefit of a structural approach is that it is passive and reliable. Mechanical/thermal weakening and removal is not passive. The annual operational cost may be higher for this alternative than for the structural alternatives in some years, but may be nothing more than preparation and planning costs during years without ice jam concerns.

5.3.4 Alternative 4: No action

- Techniques
  - Real-time monitoring of river stage linked to an automated warning system that notifies appropriate individuals at pre-defined river stages.

No action beyond monitoring the river and notifying people is low-cost, and places the burden on the property owners. The property owners in this area have the opportunity to purchase flood insurance or do their own flood-hardening.

5.4 Alternative Selected for Recommendation

Two ice control structures is the preferred alternative. If no action is taken (or mechanical/thermal weakening and removal is ineffective), the city should be prepared with an engineering design and plan ready for the next time a flood occurs and constituents are motivated to spend money to reduce future damages with a structural approach.

5.4.1 Site Selection

5.4.1.1 Base case scenario site (Location A: 200 Barre Street block)

This site is an excellent location for the upstream ice control structure/bypass channel. The modeling strongly supports a benefit to cost ratio much greater than 1. However, the social and economic implications of using land currently being developed into a distillery and café, make this site less than ideal. Of the sites studied that are suitable for passive approaches to flood risk mitigation, this site is constructible and has the highest benefit to cost ratio.

Advantages: Topography adequate for a properly sized bypass channel, distance from downtown acceptable, only one land owner, no known unreasonable environmental constraints

Disadvantages: Site currently being developed

5.4.1.2 Railroad bridge site (Location A2: 300 Barre Street block)

The general concept of the railroad bridge site is the same as the base case scenario site. Because the site is less than 700 feet upstream, much of the numerical modeling analysis is still applicable. Conceptual plans for this site are included in Appendix 9. The chief limitation is the bypass channel capacity. If the base elevation of the bypass channel is such that it only conveys water during the 0.02 annual chance exceedance storm or greater, then the site is capable of conveying 2,300 cfs. Of the 45 years with ice jams, 25 of the years had ice jams occurring at flows greater than 2,300 cfs. Consequently, the bypass channel would be inadequate for 25 out of 45 years, or for 56 percent of the years with ice jam events. By contrast, the upstream ice control structure in the base case scenario was designed to convey 8,000 cfs, which is adequate for 100 percent of the flows in an ice jam year.

The railroad bridge site is smaller, but has more complex design and construction considerations because of the railroad bridge and at least two landowners. Given the various differences, some making it more expensive, and some making it less expensive, the overall cost to construct likely is at least as much or more than the base case scenario. If the capacity of the bypass channel is exceeded, the likelihood of ice blowout at the piers also increases. The expected annual damages downstream likely are very similar to those computed at the upstream ice control structure site from the report. However, because the bypass channel at the railroad bridge site conveys approximately 70 percent less water than at the base case scenario site, upstream damage is expected to increase. Consequently, the benefit to cost ratio is expected to be slightly lower, but still greater than 1.

Advantages: Distance from downtown acceptable, no known environmental constraints

Disadvantages: Site currently being developed, topography inadequate for a properly sized bypass channel, multiple land-owners involved, complex design due to railroad bridge

5.4.1.3 Former Grossmans site (Location C: 200 River Street block)

The topography and geomorphic position (inside river bend) make this a very attractive site. Additionally, although the property may be re-developed in the future, it is not in use currently. The site is 0.8 miles upstream of the base case scenario site, which itself is 0.8 miles upstream of the Main Street bridge. This additional 0.8 miles means additional ice accumulating at the ice control structure near the Main Street bridge. If too much ice accumulates at the downstream ice control structure, flood risk will increase along Stone Cutters Way immediately upstream of the Main Street bridge. This additional damage will decrease the benefit to cost ratio. The cost of construction at this site is complicated by the site's status as a brownfield. A brownfield is defined by the Environmental Protection Agency as a "real property, the expansion, redevelopment, or reuse of which may be complicated by the presence or potential presence of a hazardous substance, pollutant, or contaminant". Given the decreased benefits, compared to the base case location, and the possibility for a much higher construction cost, the benefit to cost ratio could possibly be greater than 1, but it could also be much less than 1. Additional site investigation is needed to determine whether the site is feasible.

Advantages: Distance from downtown acceptable, site not in use, only one landowner, topography adequate for a properly sized bypass channel.

Disadvantages: Environmental constraints due to soil contamination of the site.

5.4.1.4 Tractor Supply site (Location D: 300 block of Barre-Montpelier Road)

The topography of this site is ideal for an ice control structure and bypass channel. However, the site is so far upstream that only an estimated 8 percent of the ice that reaches the Main Street bridge in an ice jam event would be trapped. The cost would be lower than the base case scenario upstream ice control structure/bypass channel site, but the benefits would be significantly reduced. Consequently, the anticipated benefit to cost ratio likely is much less than 1.

Advantages: Topography adequate for a properly sized bypass channel, no known environmental constraints

Disadvantages: Too far upstream to provide adequate protection of downtown Montpelier

6.0 Recommended Alternative

DuBois & King recommends an approach using two passive ice control structures. The appendices include the supporting hydraulic, hydrologic, economic, structural, and environmental information. This alternative includes construction of the two ice control structures, the bypass channel at the upstream ice control structure, streambank restoration, and other flood damage reduction measures. This alternative provides the most comprehensive benefits to the project area.

The operation and maintenance of the ice control piers may involve removing ice accumulations after each ice jam event if the ice does not melt during the course of the event, and periodic cleaning and inspection of the basin behind the ice control piers. The ice control piers will function at their peak efficiency if the river directly upstream is free of large debris.

The measure of a plan's economic feasibility or justification is its benefit to cost ratio. To calculate the benefit to cost ratio, the dollar value of estimated total average annual benefits are projected to be realized over the plan's economic life are divided by the plan's total annual cost. The resulting quotient, or benefit to cost ratio, must be greater than 1 to justify Federal participation in water resources improvement projects. The estimated construction cost for the recommended alternative is $4,425,000 with an annual maintenance expense of $20,000 and is expected to have benefit to cost ratio of approximately 1.69:1. Details on the economic calculations can be found in Appendix 2. Location of landforms and ice control structures can be seen in the plans in Appendix 9. The plans in Appendix 9 include 4 different potential site locations for the upstream ice control structure and associated bypass channel.

Of the four options evaluated for the upstream ice control structure location, each has significant limitations. The base case scenario site (200 Barre Street block) is in the process of being developed into a distillery. The railroad bridge site (300 Barre Street block) is only large enough to pass approximately half of the streamflow events that have historically caused ice jam flooding. In other words, it likely would not decrease losses during the larger, more damaging ice jam flood events. The former Grossmans site (200 River Street block) contains contaminated soil, and adding a by-pass channel through an area of contaminated soil may be prohibitively expensive or unpermittable. The Tractor Supply site (300 block of Barre-Montpelier Road) is so far upstream that the benefit to cost ratio will be far less than is justifiable. DuBois & King recommends a suitability study and cost estimate of using the former Grossmans site (200 River Street block). DuBois & King does not recommend further investigation of the railroad bridge site (300 Barre Street block) or the Tractor Supply site (300 block of Barre-Montpelier Road).

7.0 Environmental and Cultural Resource Impacts

At and around one of the potential upstream ice control structure/bypass sites, the project team assembled (in 2010) an initial screening analysis of potential wetlands within the riverine corridor, a survey of the presence of the State-threatened eastern pearlshell mussels, and a Phase 1 hazardous, toxic and radioactive waste environmental site assessment.

7.1 Preliminary Wetlands Identification

An initial screening analysis of potential wetlands within the riverine corridor was accomplished in 2010 (Appendix 4). Wetlands were identified by visual analysis and with spot checks of soils. Sixteen wetlands were identified and mapped. The wetlands information is intended to provide guidance to planners and engineers for avoidance and minimization of wetland impacts during the process of identifying potential locations for flood control measures during the scoping phase of this project. Once actual structure locations are identified, the areas of the structures and potential ancillary development, such as access roads and upstream inundation areas, should be formally delineated.

7.2 Eastern Pearl Mussel Survey

169 state-threatened eastern pearlshell *(Margaritifera margaritifera)* were located throughout the project area, providing evidence of a fairly large and reproducing population in the Winooski River upstream and downstream of downtown Montpelier. Any instream construction will need to address potential adverse effects on these mussels during the permitting and construction phases. The report on this survey is included as Appendix 5.

7.3 Hazardous, Toxic and Radioactive Waste

Hazardous, toxic and radioactive waste information was compiled in 2010. The information was parsed out by site ID, name, location, field map number, priority/status, contaminate, and potential risk (Appendix 6).

8.0 Non-Federal Sponsor Responsibilities

If a project is to be constructed, the non-Federal sponsor (the City of Montpelier and the Vermont Agency of Natural Resources), will be required to obtain all local and state permits to perform the work. The non-Federal sponsor also will need to provide all real estate easements, and secure a disposal site for the placement of all excess materials removed from any of the sites. The sponsor is required to sign a Project Cooperation Agreement (PCA) with U.S. Army Corps of Engineers to provide their share of project costs either in cash or as real estate interests. The items will be more clearly defined if the project moves forward through the design and subsequent permitting process.

The local sponsor also will be responsible for providing for the continuing operation and maintenance of any ice control structure to ensure it continues to operate as designed, thereby providing protection against the downstream development of ice jams for its intended service life. Maintenance requirements include removal of ice and debris from the ICS, maintaining access roads, cutting and removal of woody materials, mowing grass, and monitoring and removing animal burrows. In addition, quarterly inspections should be conducted by the local sponsor, with the U.S. Army Corps of Engineers performing annual inspections. To this end, an operation and maintenance manual will be prepared as part of the plans and specifications phase and will become part of the PCA. At present, one initial concern will be to provide for the inspection and removal of woody materials and other debris that may become trapped at an ICS. It is anticipated that quarterly inspections and an annual effort to clear an ICS of larger objects will provide adequate assurance that the project will provide the intended protection. The estimated annual cost of the operation and maintenance program is $10,000-20,000 and has been included in the economic analysis of the project.

9.0 Coordination & Public Involvement

There have been a series of regular meetings between the Corps of Engineers, DuBois & King, and the City of Montpelier throughout this study. Additionally, various Federal and state agencies and technical experts from the private sector have been consulted throughout the study.

10.0 Path Forward

It is recommended that this detailed project report be approved as the basis for understanding the system constraints and necessary future steps before developing the plans and specifications for the project. The economic analysis indicates that there is at least one alternative that can be implemented that meets both federal and state regulations regarding the environmental and economic analysis. The recommendations contained herein reflect the information available at this time and current U.S. Army Corps of Engineers policies governing formulation of individual projects. They do not reflect program and budgetary priorities inherent in the formulation of a national Civil Works construction program nor the perspective of higher review levels within the executive branch.

10.1 Other considerations

Reducing the risk of ice jam induced flooding in Montpelier has technical, environmental, social, and economic implications. Recognizing this, DuBois & King evaluated several conceptual alternatives at multiple locations for the upstream ice control structure/bypass channel site. Topography and land use limited the feasibility of most potential sites for a dedicated ice control structure and bypass channel. One common element in all conceptual alternatives was an ice control structure without a bypass channel near the Main Street bridge paired with the upstream ice control structure and bypass channel. The Main Street location is key because it is just upstream of the confluence with the North Branch. The chief concern with the North Branch is that an ice jam event in the Winooski River could cause the water level in the North Branch to increase until it overtops its bank and floods the State Street area like it did in 1992. For this reason, an ice control structure just upstream of the Winooski River-North Branch confluence will stop the ice upstream of the confluence, decreasing the risk of backwater flooding from the North Branch.

The disadvantage of an ice control structure near Main Street is higher water surface elevations immediately upstream. In other words, the ice control structure trades damages downtown for damages along the Winooski River upstream of Main Street. Without a bypass channel, this site needs to be paired with another site upstream in order to reduce ice jam volume at Main Street. The upstream site provides a way for the flowing water to get around a jam and not just build up. The first reasonable site for an ice control structure and bypass channel upstream was in the 200 Barre Street block. Because ice hydraulics are technically difficult and time-consuming to model, and consequently very expensive, this site was used as the base case scenario for the upstream ice control structure with bypass channel. Other potential upstream ice control structure/bypass channel locations were evaluated by considering the anticipated differences compared to the base case scenario. The information gathered (wetlands, hazardous materials, endangered species) and computed (structural analysis, construction cost estimate, hydraulic modeling, economic modeling, and benefit to cost ratio) at the base case scenario site provide a robust, objective, and defensible assessment of the anticipated technical, environmental, and economic considerations of a passive structural approach for flood risk reduction.

Each site considered for the upstream ice control structure/bypass channel location (see Figure 4) is privately owned. As of June 2017, the base case scenario site was in the process of being developed as a distillery. 700 feet upstream in the 300 block of Barre Street, a railroad bridge crosses the Winooski River. This site has multiple private landowners and the railroad. A third site is located at the former Grossmans warehouse in the 200 River Street block across the street from Formula Ford. It is zoned industrial and not in use. The final site is between Tractor Supply and Agway in the 300 block of Barre-Montpelier Road. It is currently in agricultural use.

10.1.1 Actively-managed rubber dams

Each of the four sites listed could be appropriate for an actively-managed (such as an automatic crest height adjustment to maintain a pre-set water level) rubber dam capable of being raised or lowered to induce or break up a jam. The primary advantage is being able to manipulate the river system in anticipation of or during an ice jam event. Raising the dam would increase water levels upstream and potentially break up the ice. Lowering the dam with a solid ice cover downstream would allow water to flow under the ice cover as if it were in a close conduit. Alternating raising and lowering the dam could result in oscillations breaking up a dangerous ice sheet.

The most effective obstacle to a breakup ice run is a flat, thick, shore-fast ice cover such as a long river pool or lake. An inflatable dam located at the site of the Bailey Dam weir could be used to create this situation. The strategy would be to raise the pool in advance of freezeup to form and maintain a sheet ice cover at the elevation associated with the expected breakup discharge, say 4,000 cfs. As the breakup hydrograph passed through the city, the dam would be lowered automatically to maintain this constant freezeup stage, preserving an intact, shore-fast sheet ice cover upstream. This ice cover would, at least for a while, block the breakup ice run, providing time for the water wave to pass through and breakup the ice in the downtown section of river. If during the breakup process, ice-affected stage rise upstream became a problem, the inflatable dam could be lowered.

Historically, previous generations of water resources managers used a similar but more violent approach in the days before the Bailey Dam was lowered in 1974. Similar to the methods used to sluice logs down steep streams and rivers, operators would set wooden stop logs in the dam and, during breakup, let the dam retain the ice until the upstream water levels began to cause flooding. At this point they would use dynamite to explode the stop logs and the resulting surge of water and ice would blow out the ice in the downtown section.

The flexibility of the inflatable dam option is attractive, but a rubber dam has never been employed in the natural environment for the sole purpose of mitigating ice jams. An inflatable dam on the Mississquoi River at Highgate was not installed for the purpose of ice jam control, but downstream ice jam prevention turned out to be an unexpected benefit (Tuthill, 2001). This was accomplished by maintaining a constant freezeup stage as the breakup flood wave passed through the dam impoundment as described above. The rubber dam itself would cost only about $375,000, but the site preparation requires a concrete base, and all of the associated technical (dewatering, cofferdams, etc.), economic (cost similar to building a traditional dam), and social/political (permitting, regulatory compliance) aspects. The ability to actively manage the river in this manner is not something easily modeled. It is possible that the active management could mitigate all, or nearly all, ice jam flooding events. Additionally, active management would have the potential to decrease the duration of ice jam flooding.

DuBois & King recommends a feasibility study specifically on the applicability of rubber dams on ice jam management. Of all of the alternatives considered, the greatest damage reduction upside is with an actively-managed approach, such as a rubber dam. It may be possible to avoid a bypass channel entirely if a rubber dam can be raised and lowered. The upstream and downstream sites, if both designed with rubber dams, could be managed as a system to reduce flood risk from ice jams in Montpelier.

Because the numerical modeling approaches available in 2017 are unable to simulate the effect of rubber dam operation on ice jams, DuBois & King recommends a scaled physical model study with three scenarios:

1) Two rubber dams (one near the Main Street bridge and one between the Granite Street bridge and the River Street bridge)
    a. Specific sites for consideration are the existing dams near Main Street and near Pioneer Street.
2) One rubber dam near the Granite Street bridge (no structure near the Main Street bridge)
3) One passive ice control structure near the Main Street bridge and one rubber dam between the Granite Street bridge and River Street bridge.

This is the chief recommendation of the authors. The technical expertise and infrastructure to conduct this research exists at government, academic, and industry laboratories. This applied research study is strongly encouraged as the best option to reduce ice jam-induced flooding in Montpelier.

10.1.2 Continued and/or enhanced mechanical weakening and ice melting

The City of Montpelier is authorized to discharge treated effluent from the City's Water Resource Recovery Facility (WRRF) to the Winooski River approximately 1/2 mile upstream of the WRRF as a means of ice jam mitigation, with additional discharge points authorized up to 1,500 feet further upstream at the Bailey Avenue bridge. Conditions for the authorization include:

1. The effluent discharged must be fully treated and otherwise meet all effluent limits of NPDES Permit #3-1207.
2. The City shall inform the public of this discharge through appropriate media.
3. The volume of effluent discharged shall not exceed a flow rate of 3000 gallons per minute (the average outflow from the facility is 1.1 million gallons per day, or 1,120 gallons per minute).
4. The duration of the discharge shall not exceed that necessary to clear the ice blockage, at which time the wastewater treatment facility's entire discharge shall revert to the outfall authorized under Permit #3-1207 (although not currently authorized, a constant discharge all winter intended to melt as much of the downstream sheet ice cover as possible in advance of the natural breakup would reduce the risk of ice jam-induced flooding).
5. Upon reverting the discharge to the permitted outfall the City shall submit a written report detailing the duration and the flow rate of the alternate discharge and a narrative evaluation of its effectiveness.
6. The pipe shall be visually inspected three times each day that it is in use.

Currently, the City of Montpelier actively routed warm effluent from the city's waste water treatment plant to a point near Bailey Ave. bridge. This location is intended to melt ice in the 1992 ice jam toe area and down into Cemetery Bend. Assuming the average plant outflow rate of 1.1 MGD, an effluent temperature of 45°F, an average river width of 125 ft, a late-winter river flow of 400 cfs and sheet ice thickness of 1.5 ft, about 120 ft of ice cover could be melted per day by the following equation from Lever et al. (2000):

$$Q_{melt}=0.008\ Q_{tot}\ \Delta\ T$$

where Q_{melt} = the ice melt rate in cfs, Q_{tot} is the total flow (sum of mixed river flow and effluent) in cfs and Δ T is the difference of the mixed water temperature and the freezing point of 32.0° by:

$$\Delta\ T = \frac{Q_{river}\ T_{river} * Q_{eff}\ T_{eff}}{Q_{tot}}$$

At this theoretical melt rate, about 30 days would be needed to melt the 3500-ft-long ice cover from the Bailey Avenue bridge downstream to the ledges below the Montpelier Gage. The actual melt would likely occur in the form of a widening lead below the discharge point. Although melting using warm effluent would not provide the total solution to ice jam flooding at Montpelier, it would be a significant mitigating factor especially if deployed in conjunction with timely ice breaking of the remaining Cemetery Bend ice in advance of natural breakup.

During the 2007 ice-out, the Winooski River came within one foot of overtopping its banks. This resulted from the formation of an unusually thick freezeup ice jam that formed in the downtown reach in late December and remained there all winter. The concern was that in the event of a rapid thaw and breakup, the freezeup jam would block the breakup ice run causing severe flooding in the city. During that time, the City implemented several methods to reduce the flood risk. A crane was used to break up the ice at a location just upstream of the I-89 bridge, an excavator was used to push the ice chunks downstream, dark organic media was blown across the ice to speed up the melting process, and a temporary pump was used to discharge the treated wastewater effluent upstream of the ice blockage to melt a channel through the ice. Of all the methods utilized, the bypass pumping of the treated wastewater effluent proved to be the most effective in the flood mitigation. The temperature of the effluent was approximately 45°F. Soon after the installation of the temporary system, a channel opened in the ice and the flood water began to recede.

As a result, in December 2007, the Montpelier Public Works Department pursued and secured funding for a permanent pumping system through the Hazard Mitigation Grant Program to construct a permanent effluent bypass system. The grant was administered by the Vermont Department of Public Safety and funded through the Federal Emergency Management Agency. The City was awarded the grant and a permanent pump station and force main was completed in May 2012. Due to the high construction costs, the project had to be scaled back from the original scope of extending to the upstream side of the Bailey Avenue bridge to just upstream of the Vermont Liquor

Control building. However, the City of Montpelier still plans to extend the system as funding allows. The schedule of the extension will depend on local funding and the availability of State and Federal assistance.

In January 2013, the City of Montpelier was granted temporary authorization to utilize the effluent bypass system for flood mitigation. Again, it created an open channel in the ice. The system was also run in 2014 and 2015 with temporary authorization and reporting requirements to Vermont Department of Environmental Conservation, but was not needed in the winter of 2016 due to mild weather. In July 2016, the City of Montpelier formally requested a permit amendment to allow for the temporary relocation of the WRRF effluent under the National Pollutant Discharge Elimination System permit during winter months. The request included six optional discharge points; three currently in place and three proposed under a future expansion to the system.

DuBois & King believes the pumped effluent and the crane for breaking up ice are useful, particularly for potential ice jam events with limited ice volumes. However, the energy available in the limited quantity of 45°F effluent is insufficient to mitigate ice jam flooding by rapidly melting moderate to thick ice volumes. Consequently, although these thermal alternatives may be beneficial as advance measures, physical ice control structures are recommended.

11.0 References Cited

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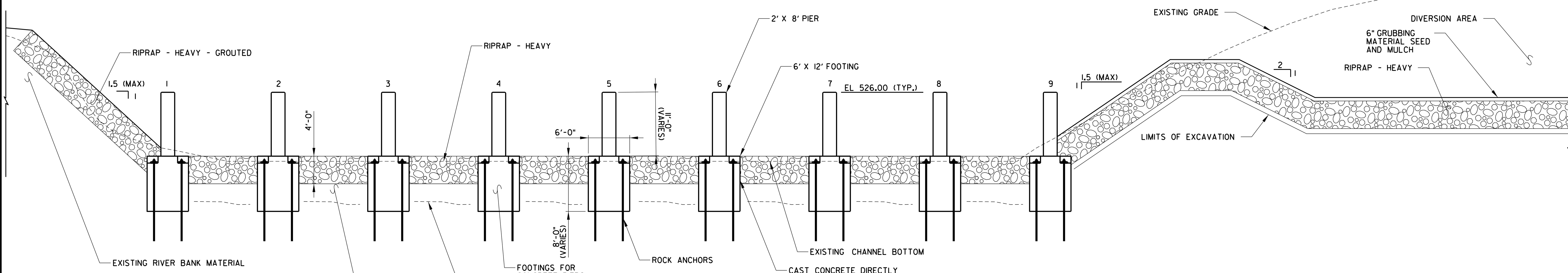
MAY 2010 NYD A/E BORDER



NOTE:

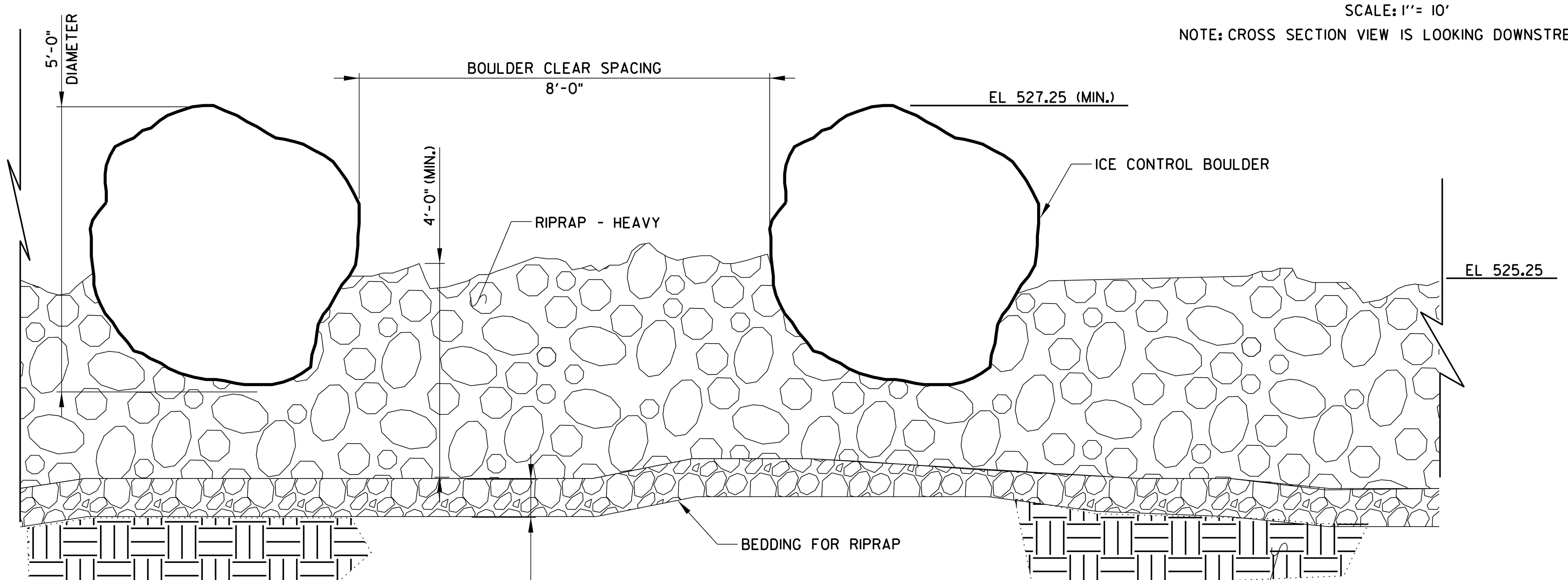
GEOTECHNICAL SOIL BORINGS WERE NOT AVAILABLE DUE TO SITE ACCESS RESTRICTIONS. ROCK ANCHOR PIER FOUNDATIONS WERE INCORPORATED TO PROVIDE A MORE CONSERVATIVE CONSTRUCTION ESTIMATE.

TYPICAL RIVER BANK AND ICE CONTROL STRUCTURE SECTION

10' 0 10'

SCALE: 1"= 10'

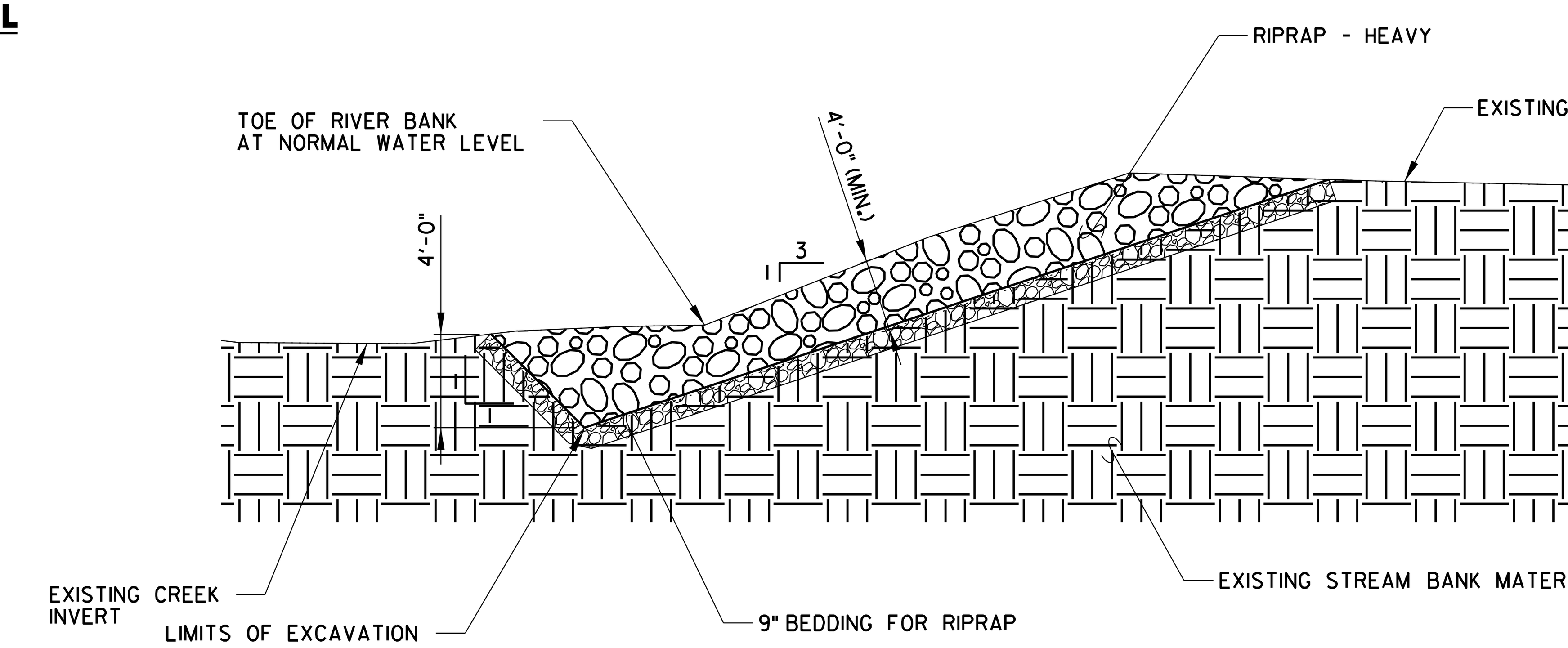
NOTE: CROSS SECTION VIEW IS LOOKING DOWNSTREAM



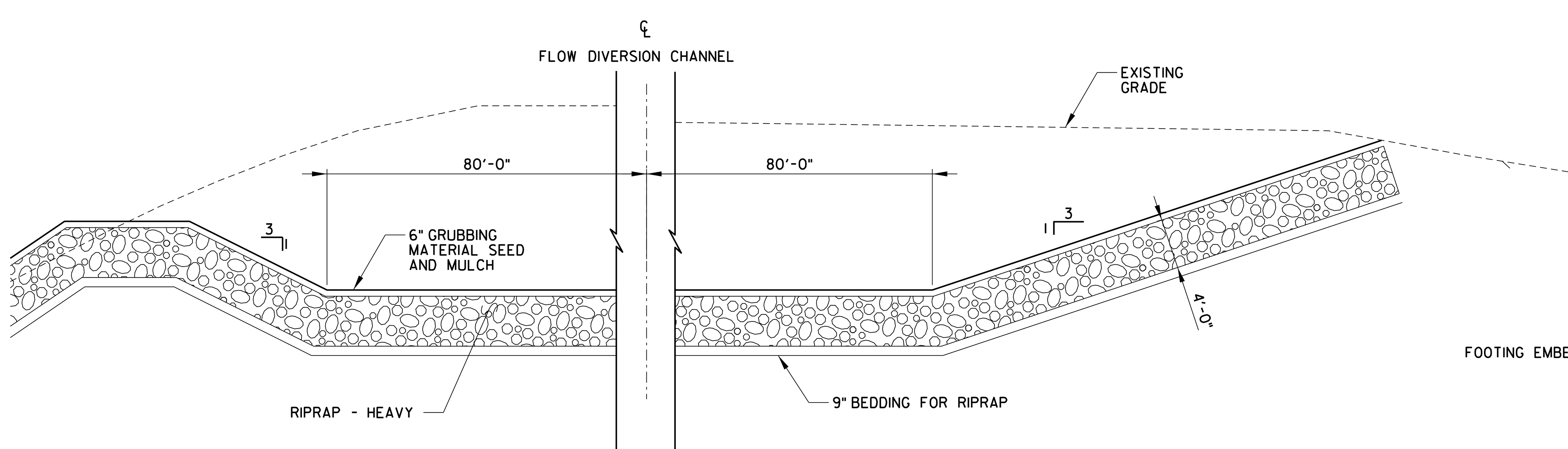
ICE CONTROL BOULDER DETAIL

2' 0 2'

SCALE: 1"= 2'



TYPICAL RIVER BANK STABILIZATION - ON EARTH (AS APPLICABLE)

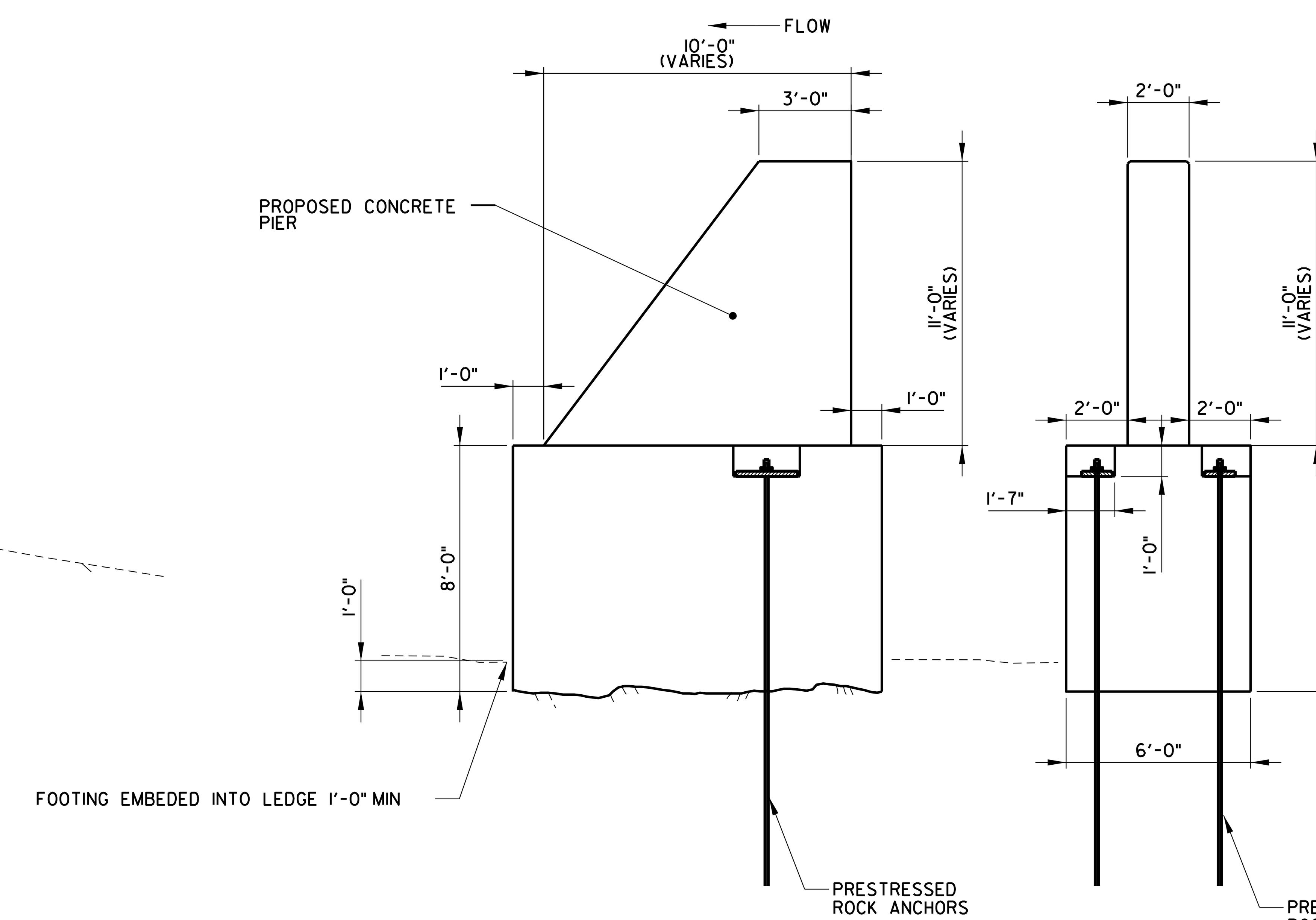


FLOW DIVERSION CHANNEL TYPICAL SECTION

10' 0 10'

SCALE: 1"= 10'

DRAFT PLANS
NOT FOR CONSTRUCTION



4' 0 4'

SCALE: 1"= 4'

ICE CONTROL STRUCTURE TYPICAL SECTIONS

US Army Corps of Engineers
New York District

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MARK	DESCRIPTION	DATE	APPR.

U. S. ARMY ENGINEER DISTRICT
NEW YORK
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SUBMITTED BY: D & K | CONTRACT NO.:
FILE NAME: $IP_SHORT_DESIGNS
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WINOOSKI RIVER
ICE CONTROL STRUCTURE
FEASIBILTY STUDY
MONTPELIER, VERMONT

DETAILS

SHEET REFERENCE NUMBER
C-301

SHEET 06 OF 06

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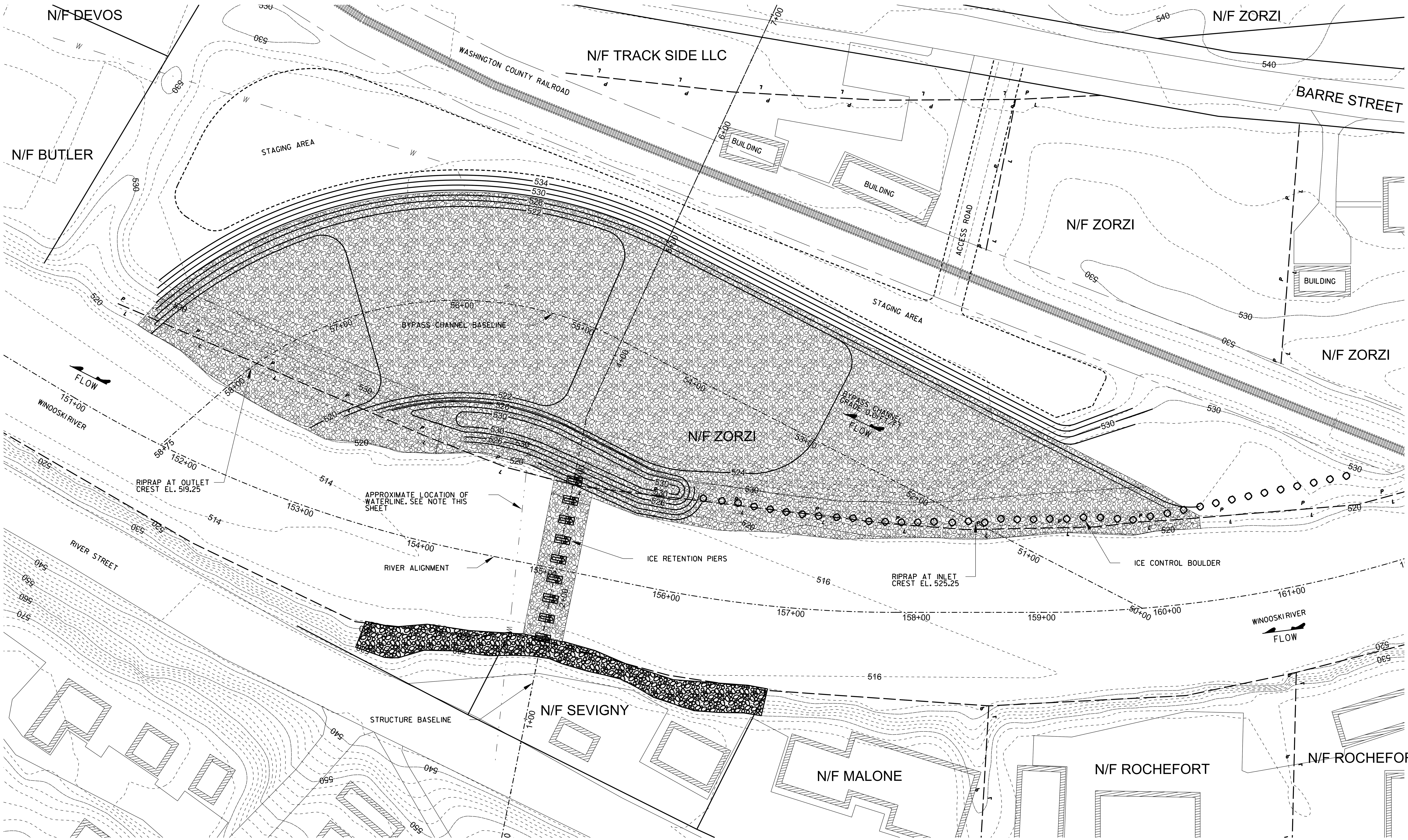

NOTE:
WATERLINE ASSUMED TO BE OUTSIDE OF ICE CONTROL STRUCTURE FOOTPRINT BASED ON MAY 2014 DISCUSSION WITH LANDOWNER AND MONTPELIER DPW. WATERLINE NOT TO BE DISTURBED.

DRAFT PLANS NOT FOR CONSTRUCTION

PROPOSED CONDITIONS SITE PLAN
LOCATION A

40' 0 40'
SCALE

LEGEND

(EXISTING)
- APPROXIMATE PROPERTY BOUNDARY
- APPROXIMATE WATER LINE
- EDGE OF PAVEMENT
- EDGE OF GRAVEL
- MAJOR CONTOURS
- MINOR CONTOURS
- RAILROAD
- BUILDING

(PROPOSED)
- CONTOURS
- BASELINE
- ICE CONTROL BOULDERS
- STRUCTURE

N

US Army Corps of Engineers
New York District

MARK	DESCRIPTION	DATE	APPR

MARK	DESCRIPTION	DATE	APPR

U. S. ARMY ENGINEER DISTRICT
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DuBois & King inc.

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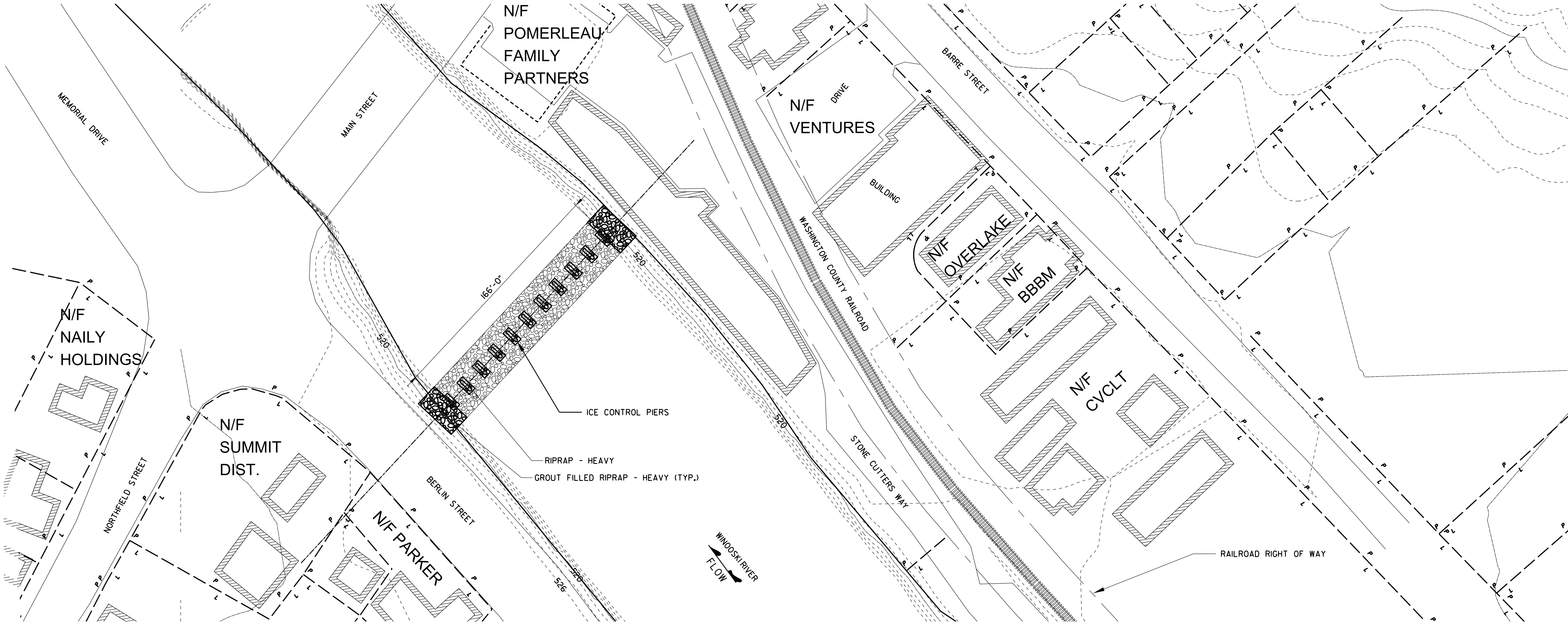
WINOOSKI RIVER
ICE CONTROL STRUCTURE
FEASIBILTY STUDY
MONTPELIER, VERMONT

PROPOSED CONDITIONS SITE PLAN
LOCATION A

SHEET REFERENCE NUMBER
C-102

SHEET 03 OF 06



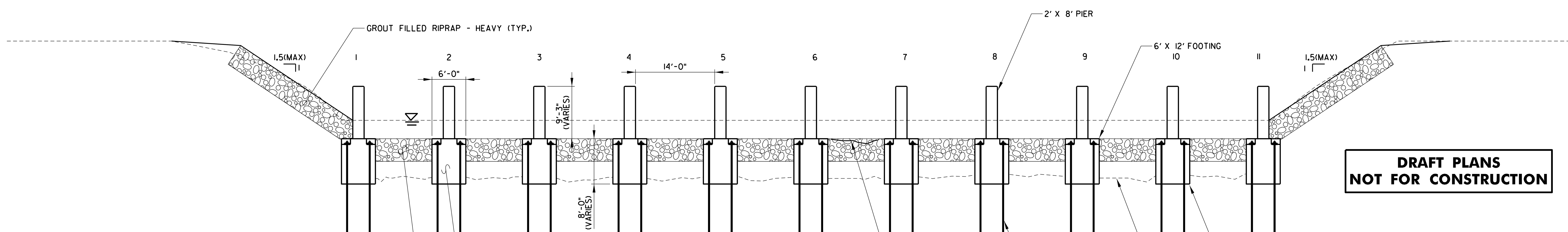
PROPOSED CONDITIONS SITE PLAN
LOCATION B

40' 0 40'
SCALE

LEGEND

- APPROXIMATE PROPERTY BOUNDARY
- APPROXIMATE WATER LINE
- EDGE OF PAVEMENT
- EDGE OF GRAVEL
- CONTOURS
- RAILROAD
- BUILDING

N



DRAFT PLANS NOT FOR CONSTRUCTION

LOCATION B
PROFILE

10' 0 10'
SCALE

NOTE:
GEOTECHNICAL SOIL BORINGS WERE NOT AVAILABLE DUE TO SITE ACCESS RESTRICTIONS. ROCK ANCHOR PIER FOUNDATIONS WERE INCORPORATED TO PROVIDE A MORE CONSERVATIVE CONSTRUCTION ESTIMATE.

US Army Corps of Engineers New York District

MARK	DESCRIPTION	DATE	APPR

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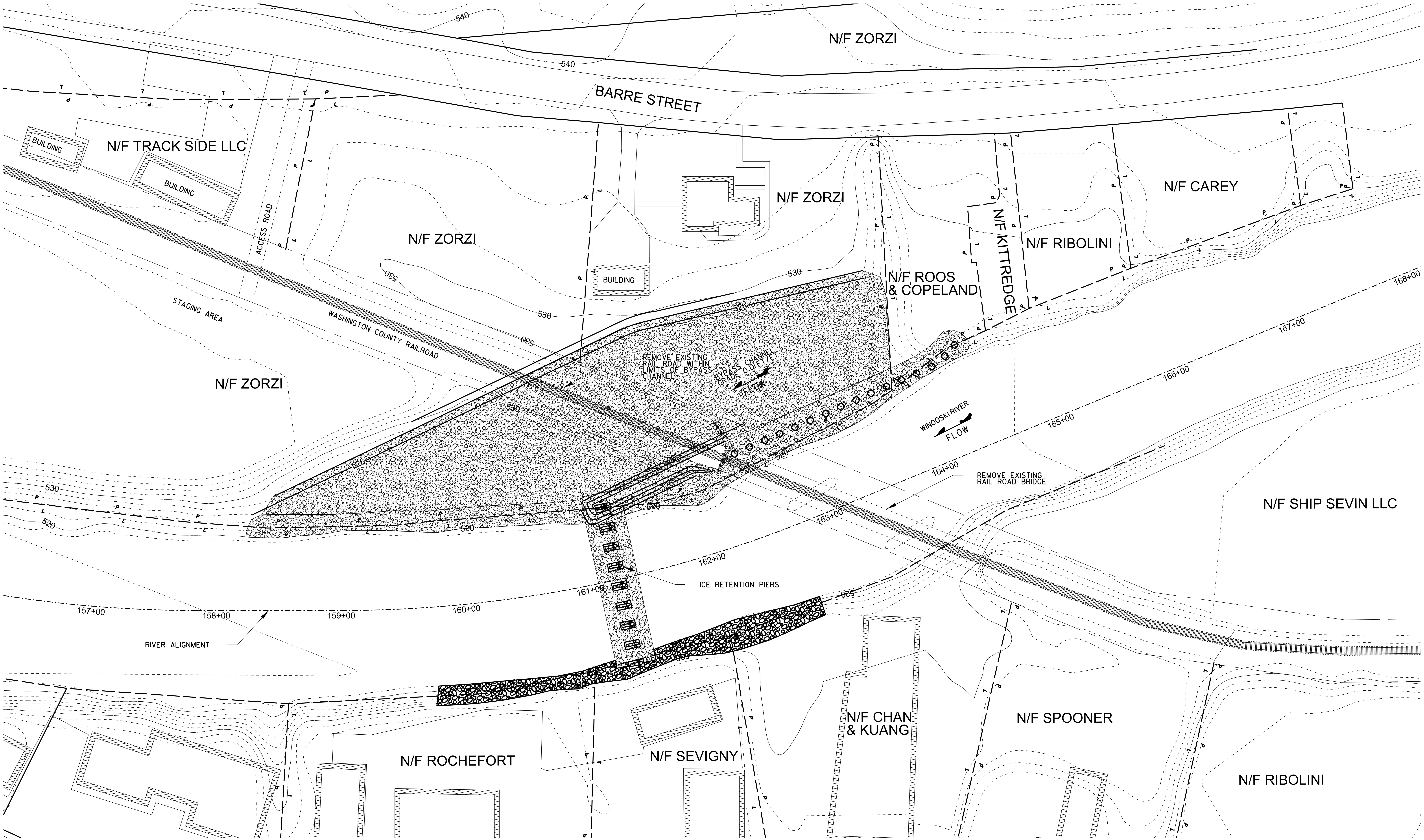
WINOOSKI RIVER ICE CONTROL STRUCTURE FEASIBILTY STUDY MONTPELIER, VERMONT
PROPOSED CONDITIONS SITE PLAN AND PROFILE LOCATION B

SHEET REFERENCE NUMBER
C-104
SHEET 05 OF 06



PROPOSED CONDITIONS SITE PLAN

LOCATION A2

40' 0 40'
SCALE

DRAFT PLANS
NOT FOR CONSTRUCTION

LEGEND

(EXISTING)

- APPROXIMATE PROPERTY BOUNDARY
- APPROXIMATE WATER LINE
- EDGE OF PAVEMENT
- EDGE OF GRAVEL
- MAJOR CONTOURS
- MINOR CONTOURS
- RAILROAD
- BUILDING

(PROPOSED)

- CONTOURS
- BASELINE
- ICE CONTROL BOULDERS
- STRUCTURE

N

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of Engineers
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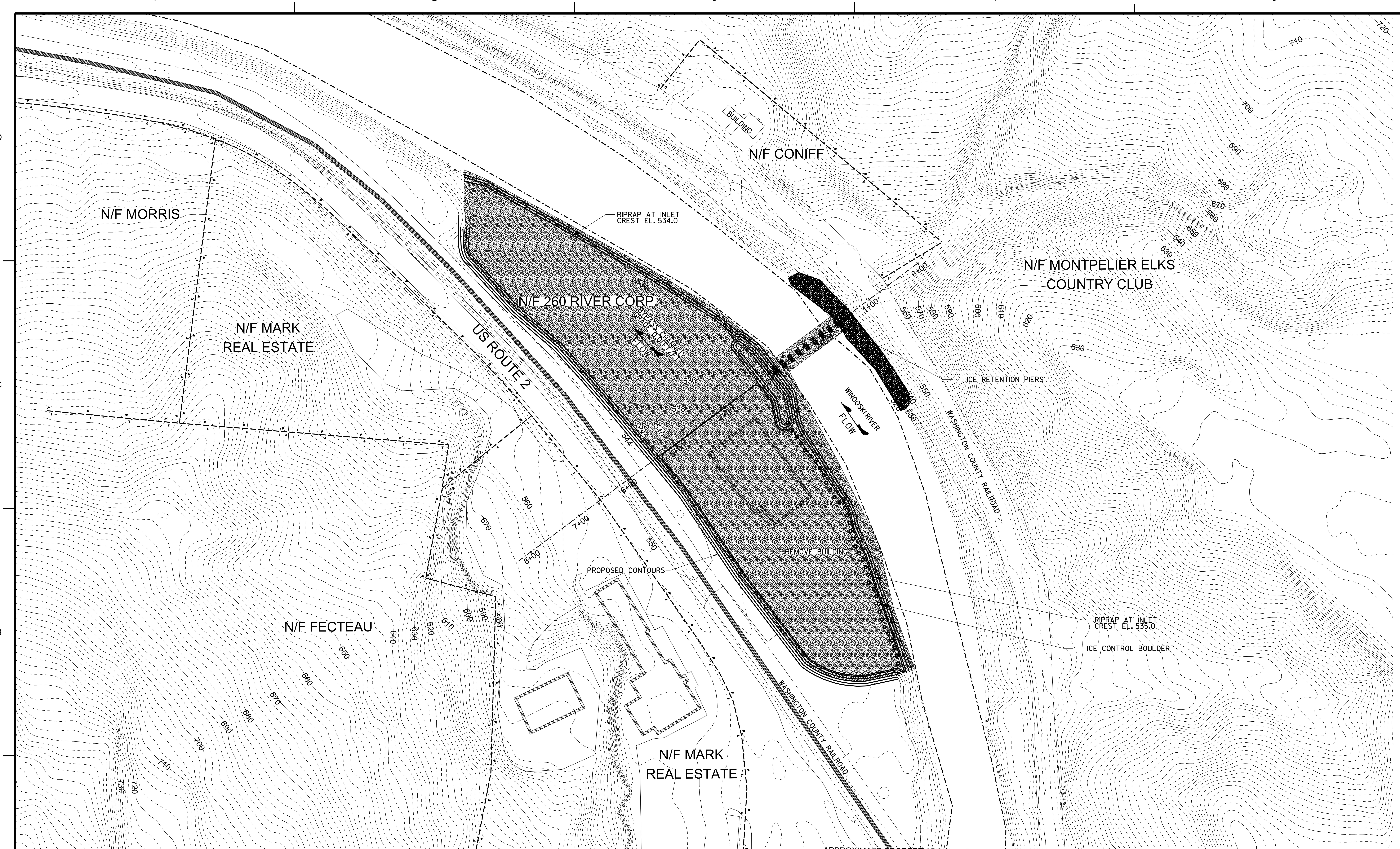
WINOOSKI RIVER
ICE CONTROL STRUCTURE
FEASIBILTY STUDY
MONTPELIER, VERMONT

PROPOSED CONDITIONS SITE PLAN
LOCATION A2

SHEET
REFERENCE
NUMBER
C-102

SHEET 03 OF 06



PROPOSED CONDITIONS SITE PLAN
LOCATION C

80' 0 80'
SCALE

DRAFT PLANS
NOT FOR CONSTRUCTION

LEGEND

(EXISTING)

APPROXIMATE PROPERTY BOUNDARY
APPROXIMATE RR ROW
EDGE OF PAVEMENT
EDGE OF GRAVEL
MINOR CONTOURS
MAJOR CONTOURS
RAILROAD
BUILDING

(PROPOSED)

CONTOURS
BASELINE
ICE CONTROL BOULDERS
STRUCTURE

N

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of Engineers
New York District

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MARK	DESCRIPTION	DATE	APPR

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WINOOSKI RIVER
ICE CONTROL STRUCTURE
FEASIBILTY STUDY
MONTPELIER, VERMONT

PROPOSED CONDITIONS SITE PLAN
LOCATION C

SHEET
REFERENCE
NUMBER
C-102
SHEET 03 OF 05

MAY 2010 NYD A/E BORDER

Plot Date: DD-MMM-YYYY HH:MM

Submitted by: USERNAME
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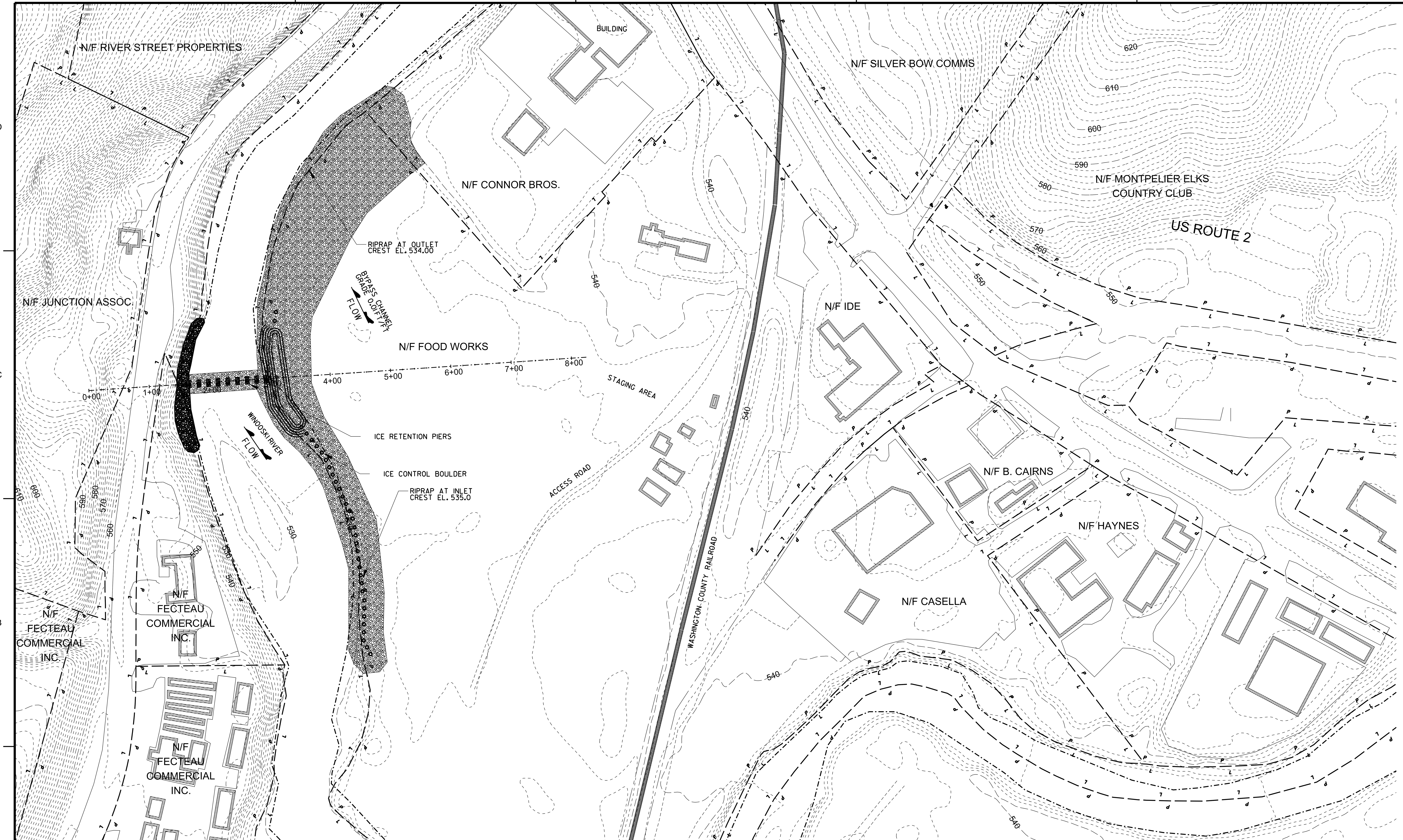

PROPOSED CONDITIONS SITE PLAN
LOCATION C

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SCALE

DRAFT PLANS
NOT FOR CONSTRUCTION

LEGEND

(EXISTING)
- APPROXIMATE PROPERTY BOUNDARY
- APPROXIMATE WATER LINE
- EDGE OF PAVEMENT
- EDGE OF GRAVEL
- CONTOURS
- RAILROAD
- BUILDING

(PROPOSED)
- CONTOURS
- BASELINE
- ICE CONTROL BOULDERS
- STRUCTURE

N

US Army Corps of Engineers
New York District

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MARK	DESCRIPTION	DATE	APPR

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DESIGNED BY: LLW	DATE: 6/14/17	
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WINOOSKI RIVER
ICE CONTROL STRUCTURE
FEASIBILTY STUDY
MONTPELIER, VERMONT

PROPOSED CONDITIONS SITE PLAN
LOCATION C

SHEET REFERENCE NUMBER
C-102
SHEET 03 OF 05