US Army Corps HEC- RTS Flood Forecasting Framework

March 6, 2018

GRCA
D. Boyd, Director of Engineering

Desired Outcome of Floodplain Management

Fundamental Outcomes

1. **Reduced Risk to Life**
2. **Reduced Property**

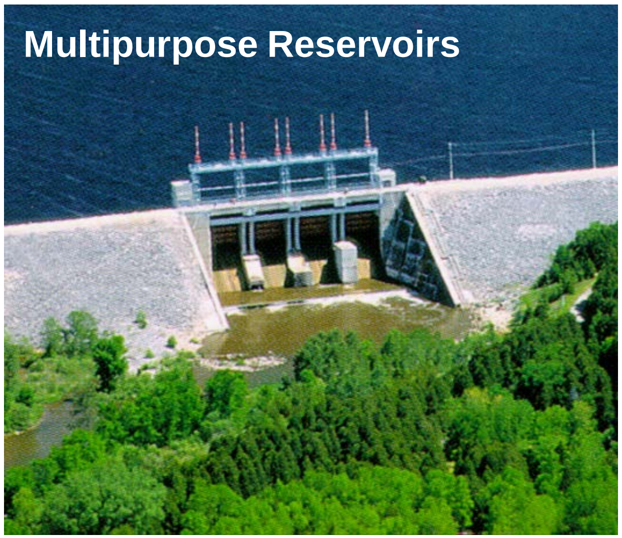
Approaches to Achieve Outcomes

1. **Structural approaches**
   a. **Dikes**
   b. **Channelization**
   c. **Dam/Reservoirs**
2. **Non Structural Approaches**
   a. **Floodplain Regulation**
   b. **Manage existing development in floodplains**
   c. **Avoidance of new development in floodplains**
   d. **Flood Warning and Flood Response Plans**

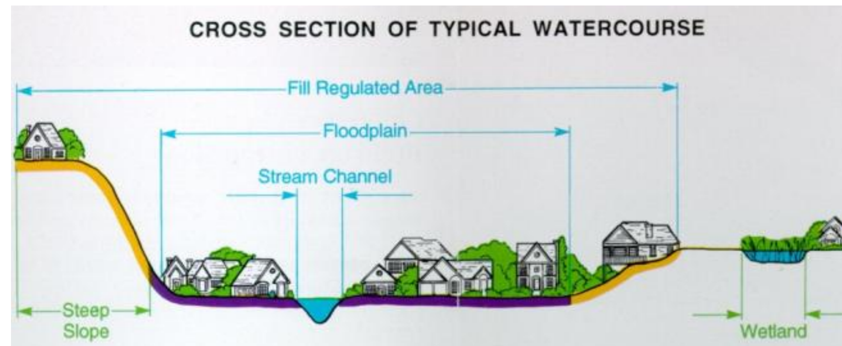
An important adaptation to climate change is preparedness plans. Flood Forecasting and Warning, Municipal flood response plans and a Floodplain Regulation.

Reducing Flood Damages

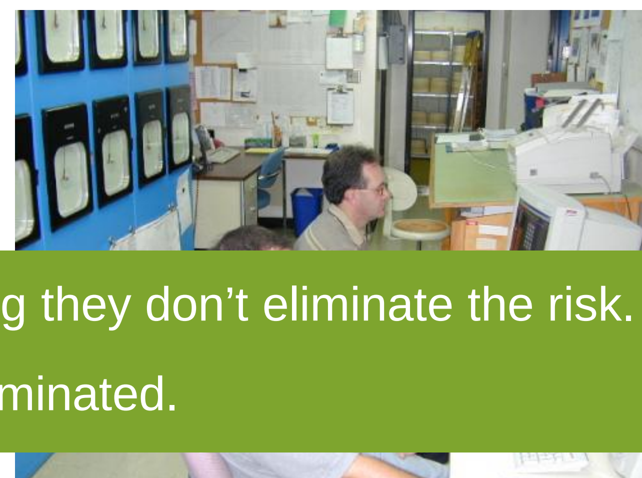
Structural Methods Keep Water Away from People	Non Structural Methods Keep People Away from Water



Floodplain Regulation



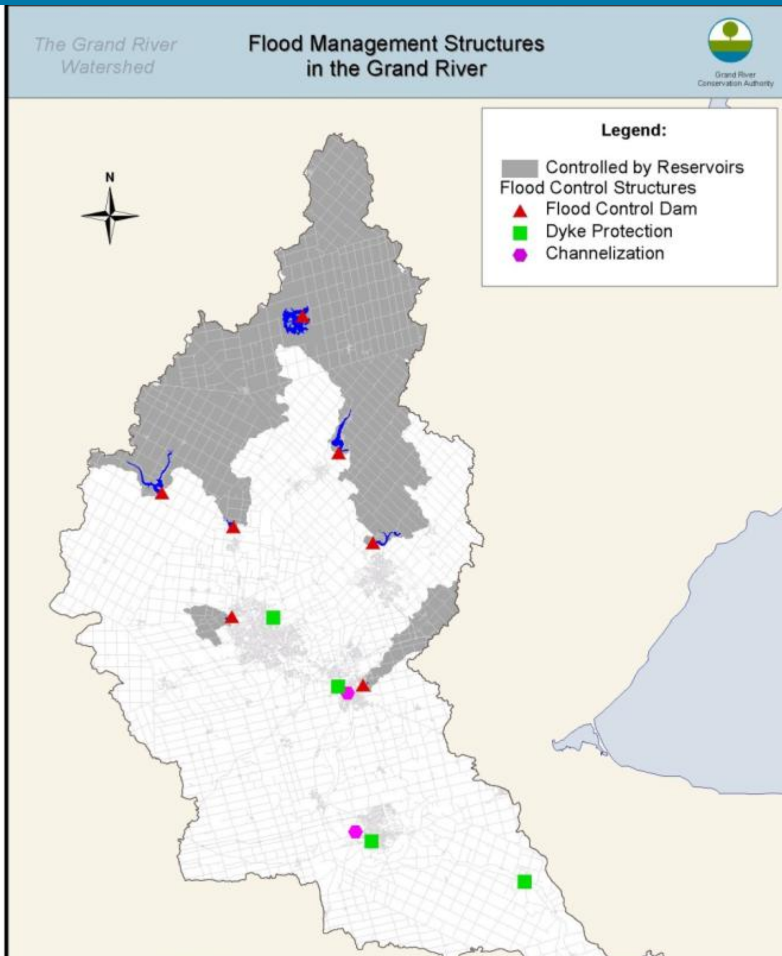
Flood Forecasting and Warning

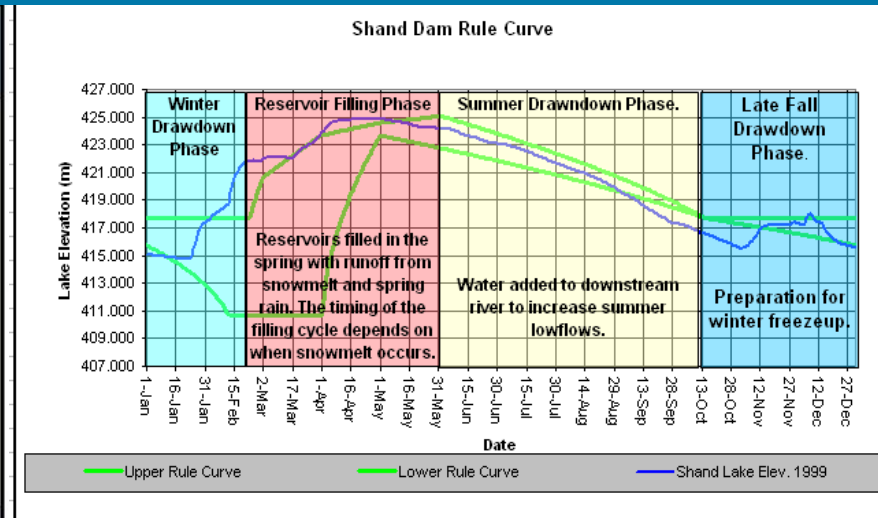


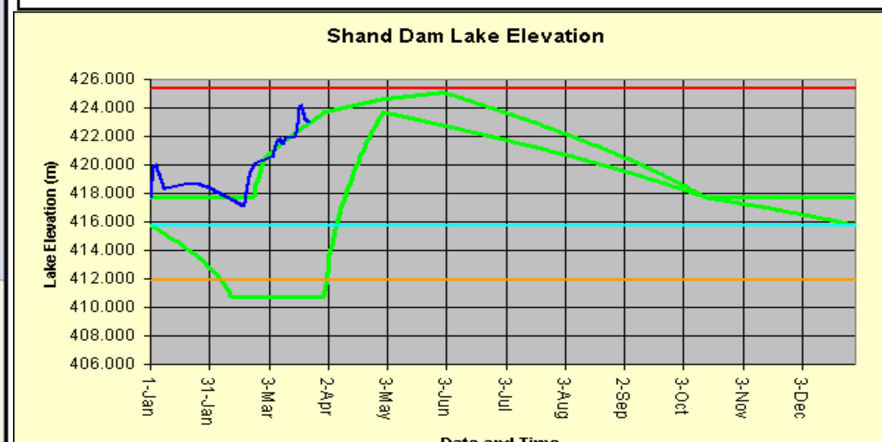
Dams and Dykes **<u>Reduce the Risk</u>** of flooding they don't eliminate the risk.

Flood Risk can be **<u>Managed</u>** not solved or eliminated.

Reducing Flood Damages



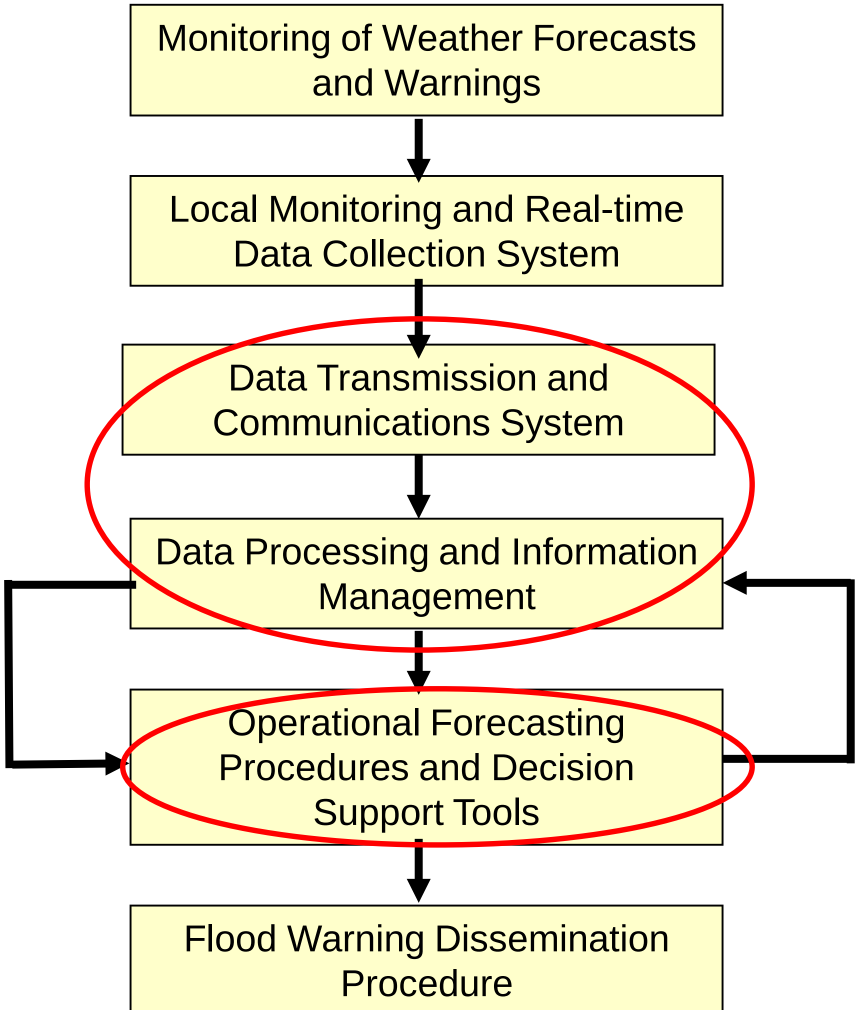


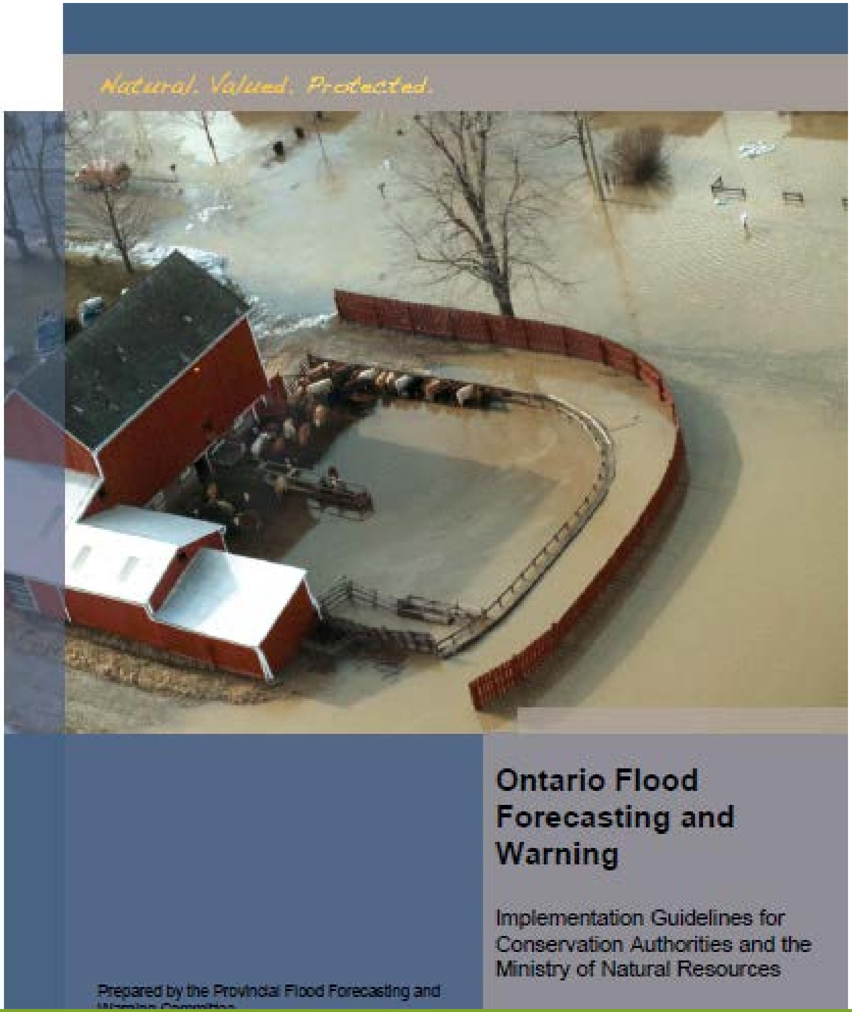


Large Dams in the Grand River Watershed regulate a portion of the drainage area.

They were purposely built to provide flood management and flow augmentation.

Flood Forecasting System Components





Provincial and CA investment in WISKI data management systems has open opportunities for sharing data in real-time allowing the opportunity for improved data products, model inputs as well as sharing tools and approaches.

Background

Several CA's currently use the GAWSER Hydrology Model to:

- Estimate flood flows for floodplain mapping
- Complete continuous simulations to estimate water budget
- Complete real-time flood forecasts
- Estimate sediment and water quality wash off

Characteristics of GAWSER:

- Based on good science
- Algorithms including its snowmelt routine are capable of modelling hydrology in southern Ontario
- Relies on readily available data and physically based data
- Uses a hydrologic response unit approach that allows for the variable response of a catchment to be represented
- Has short run times
- There is an online hydrologic modeling course provided by current model author

Current model fits business needs well but long term institutional arrangements and model adaptation to new information sources and approaches are a concern.

Background

Concerns with GAWSER

- Long term institutional arrangements of GAWSER are a concern it is currently maintained and supported by a single individual
- Runs in a DOS environment, refresh needed to allow GAWSER to run in modern operating environments

Why Now

- Several CA's will be updating floodplain mapping, hydrology will be updated as part of floodplain mapping updates
- National Disaster Mitigation Program (NDMP) provides a funding source to partially fund floodplain mapping and hydrology updates
- NDMP program funds implementation of flood forecast models as a mitigation measure
- Base information has significantly changed, SWOOP, SCOOP, LIDAR. Much better topography information.
- Increased expectations from floodplain mapping and defensibility of floodplain estimates

Large turn over in public sector staff will occur over the next 5 years. There is a need to equip the next generation of water managers with modern tools.

Business Considerations

- Updating a surface hydrology model or forecasting system is an important long term business investment decision for CA's, Province and other operating agencies.

- It has financial implications both from the cost to implement the model and from the human resources needed to effectively use and maintain the model.

- The model selected has to cover off a range of needs to make the model affordable and practical to Conservation Authorities or Province to maintain.

- A broad user base in the consulting industry is important to allow out sourcing of work, competitive bidding and recruitment of public sector staff.

Models have to be founded on good science but must make sound business sense. The business considerations are equally as important.

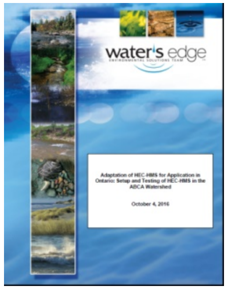
Desired Characteristics of a Hydrologic Model

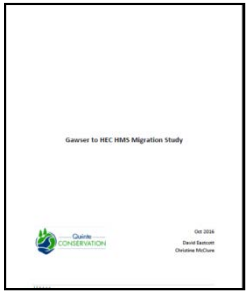
- Similar capabilities as the GAWSER model, able to represent Ontario hydrology.
- Ability to support flood flow estimates, continuous simulation, real-time forecasting, sediment and water quality wash off.
- Physically based
- Affordable
- Well documented
- Supported, solid resourcing for long term support
- Broad user base particularly in the consulting community
- <u>Good institutional arrangements</u>
  - continued support and development, training, viability of the model into the future.

The opportunity to update models doesn't occur often, these models once built will likely be in use for the next couple of decades so it important to make considered decisions.

Collaboration Efforts to Date

- Initially contacted HEC in August of 2015.
- Meeting held with HEC staff, CA's, GAWSER model authors, MNRF and EC March 1st 2016 prior to last years tech transfer workshop.
- Purpose of meeting was to explore potential to enhancements to HEC-HMS and communicate capabilities of GAWSER model used by several CA's.
- Outcome from meeting was an agreement to identify desired enhancements to HEC-HMS to improve it's application in Ontario.
- Three CA pilot projects completed to test and assess HEC-HMS.
- Desired enhancements identified over 2016.





The opportunity to work with the US Army Corps Hydrologic Engineering Centre (HEC) presented itself and a collaboration effort was initiated.

Current Identified Desired HMS Enhancements

1 **<u>Muskingum Cunge Routing - (complete)</u>**
2 **<u>Green Ampt Infiltration - (near complete)</u>**
3 **<u>Snowmelt Model for Shallow Packs – (in the works)</u>**
4 Closed Drainage Systems
5 Estimating Runoff Timing Parameters from High Resolution DEM's
6 Hydrologic Response Units
7 Seasonal Parameter Adjustments
8 Linacre Potential Evapotranspiration
9 **<u>Linear Reservoir Baseflow– (starting)</u>**

A technical advisory team has been formed to provide technical advice directly to HEC staff.

The arrangements with HEC are like a co-operative, various parties contribute to enhancements and the whole user community benefits.

Technical Advisory Committee

Dr. Hugh Whiteley

Original GAWSER model author

Dr. Harold Schroeter

Author of snowmelt model in GAWSER, maintains, adapts and distributes current GAWSER model.

Dr. Kevin Shook

Canadian expert prairie closed drainage and variable contributing Hydrology. Practical flood forecasting experience

Dr. John Perdikaris

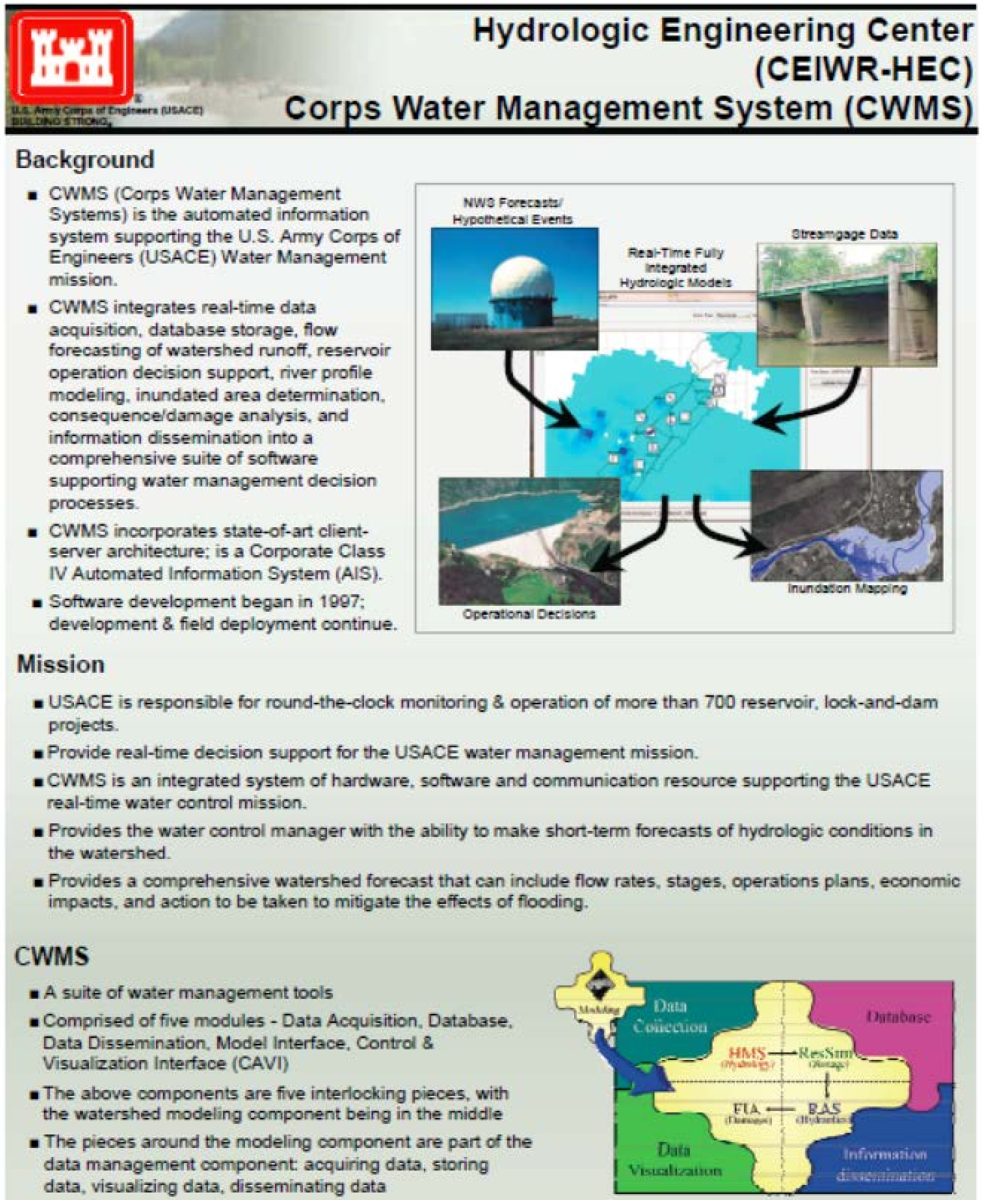
Senior hydro technical engineer Ontario Power Generation, applied HEC-HMS experience.

Chris Doherty

Environmental Water Resources Group Ltd., decades of applied consulting experience.

Advisory committee provides technical comments and feedback to staff at HEC

HEC-Real Time System


Hydrologic Engineering Center (CEIWR-HEC)
Corps Water Management System (CWMS)

U.S. Army Corps of Engineers (USACE)
BUILDING STRONG

Background

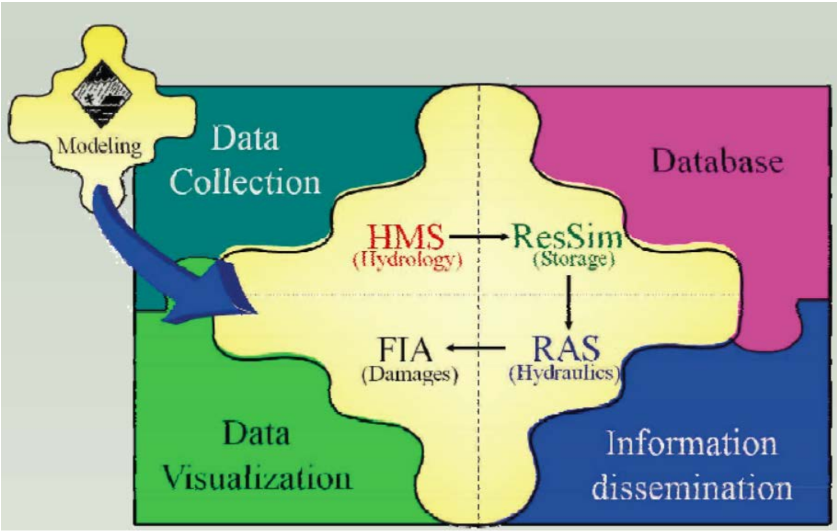
- CWMS (Corps Water Management Systems) is the automated information system supporting the U.S. Army Corps of Engineers (USACE) Water Management mission.
- CWMS integrates real-time data acquisition, database storage, flow forecasting of watershed runoff, reservoir operation decision support, river profile modeling, inundated area determination, consequence/damage analysis, and information dissemination into a comprehensive suite of software supporting water management decision processes.
- CWMS incorporates state-of-art client-server architecture; is a Corporate Class IV Automated Information System (AIS).
- Software development began in 1997; development & field deployment continue.

Mission

- USACE is responsible for round-the-clock monitoring & operation of more than 700 reservoir, lock-and-dam projects.
- Provide real-time decision support for the USACE water management mission.
- CWMS is an integrated system of hardware, software and communication resource supporting the USACE real-time water control mission.
- Provides the water control manager with the ability to make short-term forecasts of hydrologic conditions in the watershed.
- Provides a comprehensive watershed forecast that can include flow rates, stages, operations plans, economic impacts, and action to be taken to mitigate the effects of flooding.

CWMS

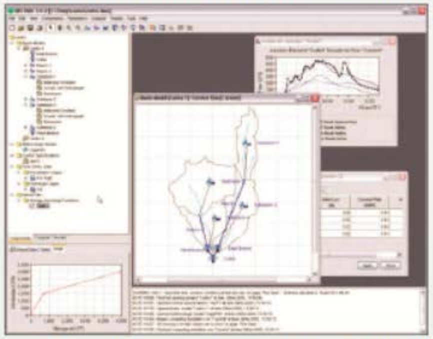
- A suite of water management tools
- Comprised of five modules - Data Acquisition, Database, Data Dissemination, Model Interface, Control & Visualization Interface (CAVI)
- The above components are five interlocking pieces, with the watershed modeling component being in the middle
- The pieces around the modeling component are part of the data management component: acquiring data, storing data, visualizing data, disseminating data



- HEC-RTS essentially the same functionality as CWMS.
- HEC-RTS is designed to use the Corps HEC-DSS database and is designed to run on a Desktop PC.
- There is ability to inject output from other flow forecast models. Output from other models would be injected into the HEC-DSS database

HEC-Real Time System

Hydrologic Modeling System (HEC-HMS)



Simulates the precipitation-runoff processes of watershed systems. Represents a wide range of hydrologic systems. Hydrographs produced by HEC-HMS are used directly or in conjunction with other software to support many types of studies.

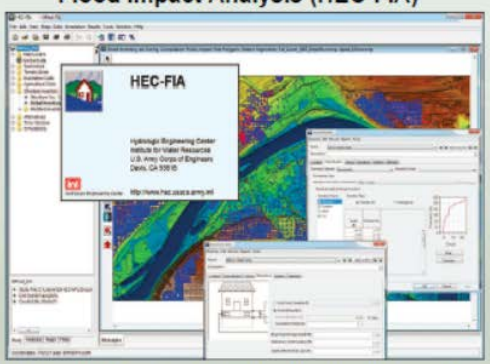
Reservoir System Simulation (HEC-ResSim)

Simulates the operation of systems with one or more reservoirs to meet storage flow targets within a river network. Operating goals are met by rules defining operational limits. Hydrographs produced by HEC-ResSim are used directly or passed to other software.

River System Analysis (HEC-RAS)

Computes river velocities, stages, profiles, and inundated areas given streamflow & geometry. Steady & Unsteady Flow; Sediment Transport; Water Quality & Temperature. Stages (i.e., hydrographs, values) & inundation maps produced by HEC-RAS are used directly or passed to

Flood Impact Analysis (HEC-FIA)



Calculates post- or forecasted-flood consequences for a user-specified event. Used to determine flood damage reduction benefits attributed to individual flood-control

- Modular design, modules can be adapted or additional modules integrated.
- Reservoir optimization
- Real-time **inundation** mapping.
- Ability to estimate **flood damages** and **potential risk to life** incurred and avoided.
- Corps of Engineers report up to congress each year on the effectiveness of mitigation projects.

In the future is will be possible to report on flood damages and potential risk to life incurred and avoided where RTS is fully implemented. Has application in special policy areas and to the dam safety program.

Example Summary of February 2018 Flood

Location	Water Course	Natural Flow (m^3/s)	Regulated Flow (m^3/s)	Flood Frequency Natural (yr)	Flood Frequency Regulated (yr)	Flow Reduction %
Legatt-Grand Valley	Grand River	245	--	5o to 100 yr		
Marsville	Grand River	350	--	10 to 20 yr		
Shand Dam	Grand River	402	164	10 to 20 yr		59%
Elora	Grand River	402	164	10 to 20 yr	2 to 5 yr	59%
Irvine Salem	Irvine River	151	--	5 to 10 yr		
West Montrose	Grand River	565	254	5 to 10 yr	2 to 5 yr	55%
Bridgeport	Grand River	1257	481	10 to 20 yr	2 to 5 yr	62%
Doon	Grand River	1265	513	10 to 20 yr	2 to 5 yr	59%
Galt (no ice)	Grand River	1408	730	10 to 20 yr	5 to 10 yr	48%
Galt (with ice jam)	Grand River	1408	1100	10 to 20 yr	20 to 50 yr	22%
Paris	Grand River	1408	1100	10 to 20 yr	20 to 50 yr	22%
Brantford (no ice)	Grand River	1921	1040	20 to 50 yr	5 to 10 yr	46%
Caledonia	Grand River	1955	1210	20 to 50 yr	10 to 20 yr	38%
York	Grand River	1955	1210	20 to 50 yr	10 to 20 yr	38%
Dunnville	Grand River	2006	1226	5o to 100 yr	10 to 20 yr	39%
Above Drayton	Conestogo River	299	--	10 to 20 yr		
Drayton	Conestogo River	316	--	20 to 50 yr		
Moorefield	Moorefield Creek	100	--	5 to 10 yr		
Conestogo Dam	Conestogo River	480	169	10 to 20 yr		
Glen Allan	Conestogo River	480	169	10 to 20 yr	2 to 5 yr	65%
St. Jacobs	Conestogo River	555	174	10 to 20 yr	< 2yr	69%
Floradale	Canagagigue Creek	74	--		10 to 20 yr	
Woolwich Dam	Canagagigue Creek	80	15		10 to 20 yr	81%
Below Elmira	Canagagigue Creek	120	50		10 to 20 yr	58%
Armstrong Mills	Speed River	73	--	5 to 10 yr		
Guelph Dam	Speed River	103	35	5 to 10 yr		66%
Victoria Rd Gauge	Speed River	103	35	5 to 10 yr	5 to 10 yr	66%
Eramosa River	Eramosa River	47	--	20 to 50 yr		
Speed River Edinburgh	Speed River	146	98	10 to 20 yr	20 to 50 yr	33%
Speed River Beaverdale	Speed River	153	95	10 to 20 yr	10 to 20 yr	38%
Speed River Preston	Speed River	153	95	10 to 20 yr	10 to 20 yr	38%
Nithburg	Nith River	241	--	5 to 10 yr		
New Hamburg	Nith River	405	--	20 to 50 yr		
Ayr (estimated)	Nith River	439	--	20 to 50 yr		
Canning	Nith River	356	--	10 to 20 yr		
Whitemans Creek	Whitemans Creek	103	--	> 100 yr		

Note: Regulated Flow is with reservoir regulation; Natural Flow is without reservoir regulation
Brantford is only reported with no ice jam,
Galt is reported with no ice jam and the flow from the release of the ice jam

- Example of current summary from February 2018 flood.
- Results are draft and still under review
- They provide a summary of the severity of the flood and flow reduction provided by **flood management** reservoirs.
- In the future it will be possible to report on damages and potential risk to life incurred and avoided.
- This report is important to justify the value of the investment by the Provincial, municipalities and CA's to maintain flood management infrastructure.

Integration of Floodplain Mapping with Emergency Response

Municipal Emergency Plan with respect to flood

Flood Inundation Mapping

GRCA Flood Warning →

1. **Floodplain residents and businesses that need to be warned**
2. **Expected Transportation Affected**
3. **Expected critical infrastructure affected**

→

1. **Declaration of an emergency**
2. **Evacuation of residents**
3. **Closure of roads, streets, bridges**
4. **Critical infrastructure shutdown**

Documenting process and procedures supports succession planning, business continuity and preparedness in general.

Flood Inundation mapping for operational flood response is equally as important as floodplain regulation mapping. Very important to reduce risk to life for existing development in a floodplain.

The Regulatory flood is one event in a continuum of floods to the PMF flood.

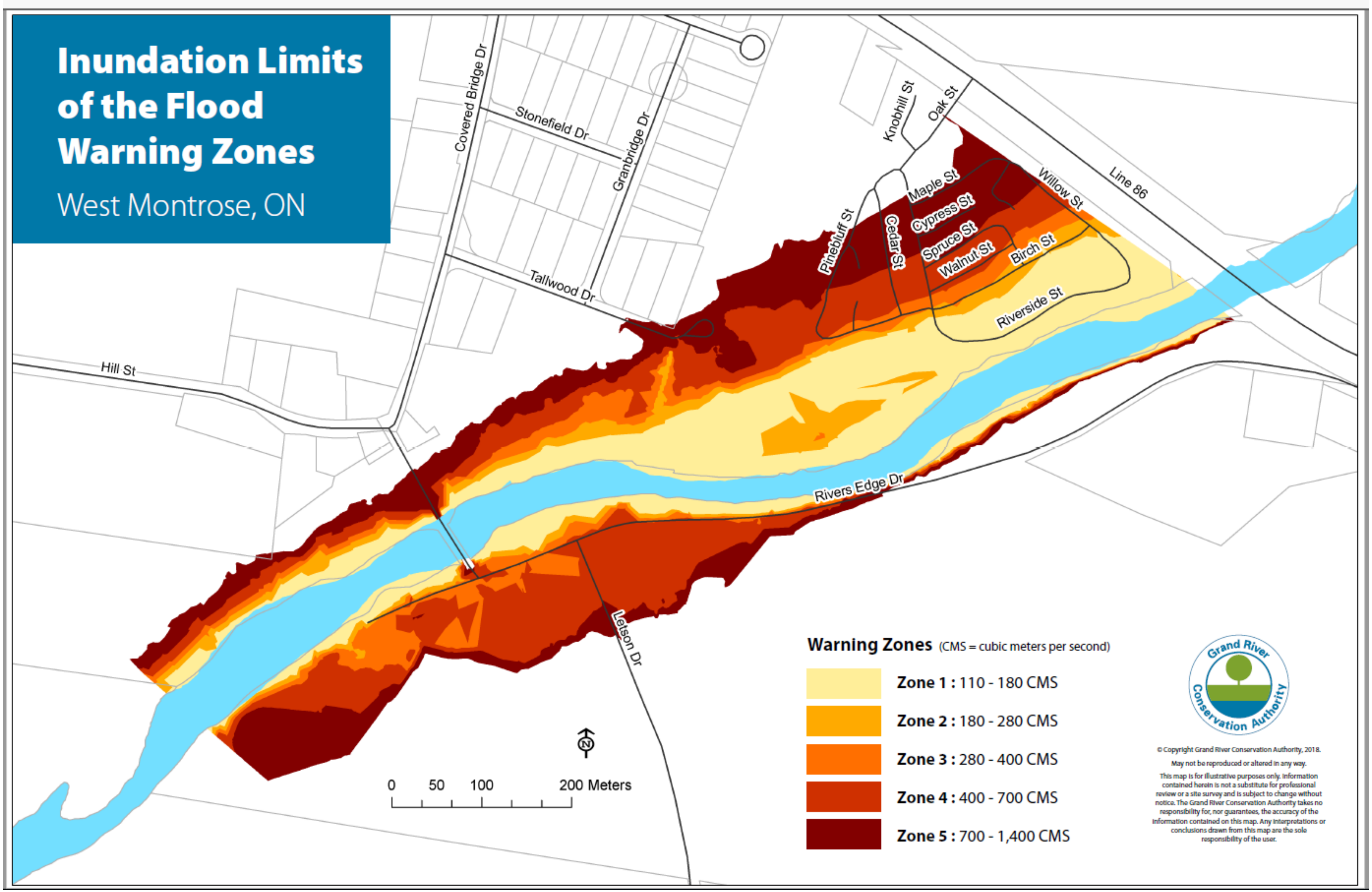
West Montrose Flood Warning Mapping Flood Zones and Flood Messages

Flood Warning Zone	Description	Flood Warning Zone Flow Threshold (cms)	West Montrose Campground	Village of West Montrose
Between the Banks	Bank full flow 0 -110 cms. (non flood condition)	Up to 110	Normal condition no watch or warnings	Normal condition no watch or warnings
Level 1	Flow 110 to 180 cms (level 1 flood flats flood)	Up to 180	Flood Warning Flood Flats Campground	Flood Watch
Level 2	Flow 180 to 280 cms (level 2 flood flats flood to channel capacity)	Up to 280	Flood Warning Entire Campground	Flood Watch Entire Village
Level 3	Flow 280 to 400cms (level 3 flooding of houses in West Montrose, closure of Rivers Edge Drive)	Up to 400	Flood Warning Entire Campground	Flood Warning Entire Village
Level 4	Flow 400 to700 cms (level 4 severe flooding of residents 1974 Maximum observed was 674 cms, also cover area affected by Feb 1981 ice jam flooding 322.9 m)	Up to 700	Flood Warning Entire Campground	Flood Warning Entire Village
Level 5	Flow 700 to 1400 cms (level 5 severe flooding of residents, potential for flooding to the limits of the Regulatory Floodplain) Potential for loss of covered bridge exist, water levels at bridge soffit at 750 m3/s.	Up to 1400	Flood Warning Entire Campground	Flood Warning Entire Village

- New flood zone mapping has been provided to the township and used as input to the community alert systems.
- This mapping can also be used to plan actions during a flood such as who needs to be warned versus who needs to be evacuated.

New flood zones will be integrated with Municipal Emergency Plans for flood emergencies. Flood zone maps are used rather than real-time inundation maps specific to an individual flow. Zones provide a buffer.

West Montrose Flood Status Web Page



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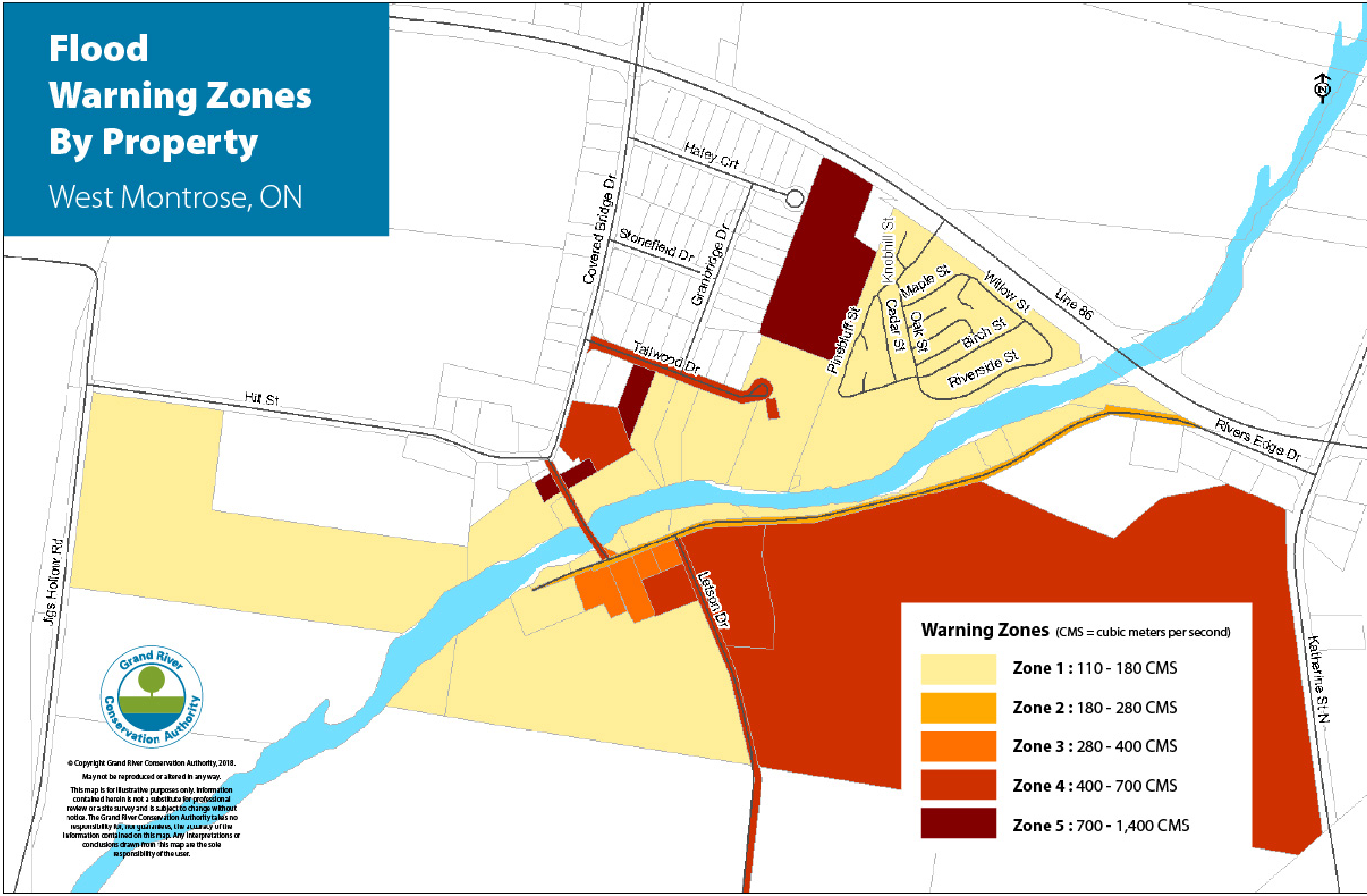


Public Language Brochure to Communicate Flood Zone Maps

Causes of floods

Floods can occur at any time of year and have a variety of causes. The most common reasons for floods are:

- extreme rainfall, which can occur at any time of year
- high temperatures in the winter and spring that cause snow and ice to melt quickly
- ice jams in the winter and spring, when large amounts of ice become lodged in the river channel, causing water to back up and spill over the banks

Flood forecasting

The GRCA monitors weather information, river flows, snow pack and ice conditions in order to predict when floods will occur and how high the water may rise. Five river gauges and four rain gauges in the Nith River watershed provide information on current conditions.

Flood messages

When flooding is possible or about to occur, the GRCA issues flood messages to municipal emergency management officials and the media.

There are three types of messages:

1. High Water Safety Bulletin: The GRCA is tracking weather conditions to assess the potential for flooding. Rivers, streams and ponds may be unsafe for recreational and other activity.

2. Flood Advisory: Flooding is possible. Municipalities and individuals should prepare.

3. Flood Warning: Flooding is occurring or is about to occur. Municipalities and individuals should take action to deal with flood conditions. This may include road closures and evacuations.

Flood response

When the GRCA issues a flood warning, it is sent to the Waterloo Regional Police and the Wilmot Township Flood Co-ordinator. They implement their flood response plans. In a serious emergency, the township may activitate its Emergency Operations Centre to oversee the flood response.

- The township flood co-ordinator will work with township staff to close roads, shut down utilities and take other action to protect lives and property.
- The police will warn households and businesses within the area to be affected, based on the warning levels shown on the map. This will be done through door-to-door visits by police officers.
- Warnings may be issued at different times to different levels, depending on the conditions causing the flood. In most cases, properties will receive only one warning.

Turn over for important information on **dealing with floods** ▶

Flood warning levels

Flood emergency officials have developed a warning system that is based on the rate of flow of water in the Nith River during floods. Water flows are measured in "cubic metres per second" (m^3/s). That is the amount of water flowing past a fixed spot in one second.

Residents should locate their property on the map to see how it is affected at various warning levels.

Normal summer low flow: 1.5 m^3/s (cubic metres per second)

Warning Level 1: 142 - 175 m^3/s

Warning Level 2: 175 - 300 m^3/s

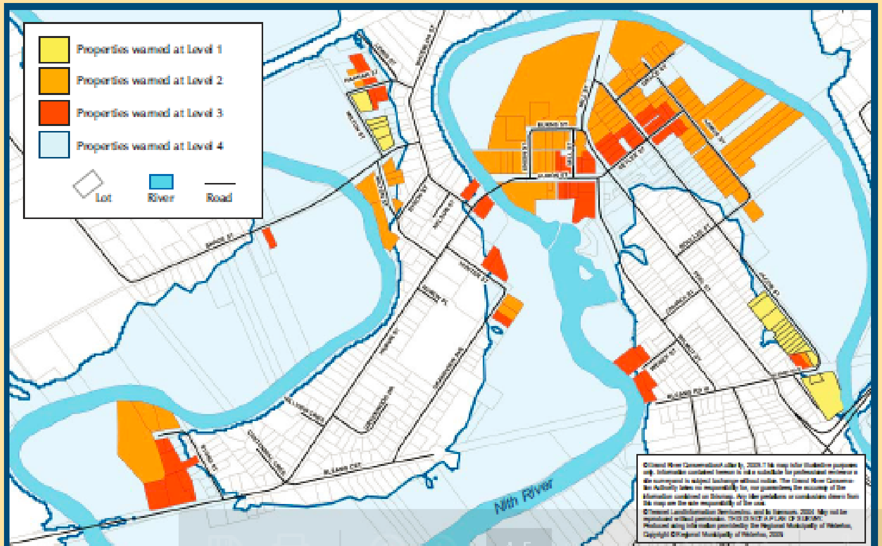
Warning Level 3: 300 - 500 m^3/s

Warning Level 4: more than 500 m^3/s
Warning Level 4 includes the land that would be flooded if a huge storm, the size of Hurricane Hazel in 1954, were centred directly over New Hamburg. The flows would be about 1,000 m^3/s. This is known as the "regulatory flood" and is used to determine the parts of New Hamburg where construction and new development is restricted. Anyone considering building, grading or other construction activity in this area must consult the Resource Planning department of the GRCA. More information is available in the "Planning and Regulations" section of the GRCA website.

Ice jams: Ice jams can develop quickly and can cause flooding at any flow level or make flooding worse than under ice-free conditions. The GRCA's water level monitoring gauges can sometimes detect sudden changes in water level caused by ice jams.

New Hamburg properties warned in the event of Nith River flooding

If flooding is about to occur, the police will warn households and businesses within the area to be affected.



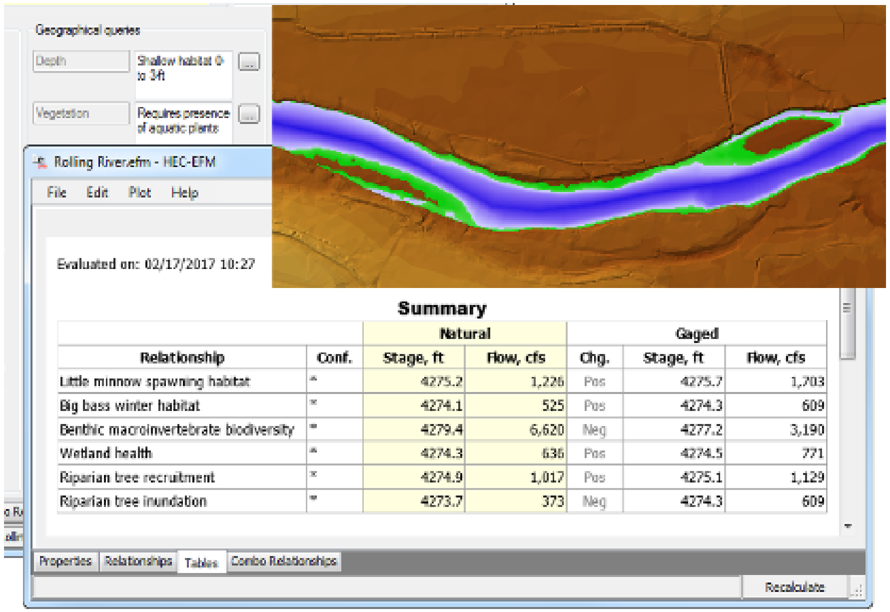
April 1975: Warning Level 3
One of the largest floods in New Hamburg history, with 30 homes and businesses affected. Flows reached 453 m^3/s.

Photo by Dave Bender

April 2008: Warning Level 3
Spring runoff produced a peak flow of 350 m^3/s resulting in many flooded streets and basements.

https://www.grandriver.ca/en/our-watershed/resources/Documents/Flooding/Flooding_brochure_NewHamburg.pdf

Floodplain Mapping
Multiple Applications



Summary

		Natural			Gaged	
Relationship	Conf.	Stage, ft	Flow, cfs	Chg.	Stage, ft	Flow, cfs
Little minnow spawning habitat		4275.2	1,226	Pos	4275.7	1,703
Big bass winter habitat		4274.1	525	Pos	4274.3	609
Benthic macroinvertebrate biodiversity		4279.4	6,620	Neg	4277.2	3,190
Wetland health		4274.3	636	Pos	4274.5	771
Riparian tree recruitment		4274.9	1,017	Pos	4275.1	1,129
Riparian tree inundation		4273.7	373	Neg	4274.3	609

http://www.hec.usace.army.mil/software/hec-efm/

The Ecosystem Functions Model (HEC-EFM) is designed to help study teams determine ecosystem responses to changes in the flow regime of a river or connected wetland

1. Floodplain regulation mapping line.
2. Flood frequency mapping/flood risk mapping
3. Flood insurance assessment
4. Flood emergency response mapping/flood zone mapping
5. Dam safety HPC and emergency plans
6. Flood inundation mapping flood extent, depth, velocity.
7. Flood damage assessment.
8. Life safety modeling.
9. Floodplain/stream gauge rating curve estimates for extreme events.
10. Environmental flow ecological habitat monitoring.
11. Assimilative capacity and water quality modeling.
12. Spills travel time modeling.
13. Ice characterization and assessment mapping.
14. Geomorphology and slope stability studies.

Collaboration Efforts to Date

- Contract initiated with Resource Management Associates Inc. and USACE HEC to complete three enhancements to HEC-HMS over 2017. Two close to completion third underway.
- Beyond the work related to HEC-HMS discussions were held with Kisters US and RMA advocating for a linkage between HEC-DSS and the WISKI Database in 2016.

- A project in the Merced Irrigation District (California) financed an integration project between HEC-DSS and Kisters WISKI database. The integrated solution was created and tested in 2016. Documentation of that linkage was created in late 2017 and will be presented today.

- The integration solution involves custom configuration of the WISKI database to share and receive data from the HEC-DSS database and installation of HEC-RTS Version **3.1.0.792** which is currently a beta version of HEC-RTS available from Resource Management Associates. A copy of this beta version is included on the workshop memory stick.

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- A memorandum of understanding (MOU) is being developed between the US Army Corps and the GRCA. This MOU is being created on behalf of the Province.

- Once in place it will allow direct contracting with the US Army Corps of Engineers Water Institute Hydrologic Engineering Centre. This will facilitate easier project co-ordination and enhanced training opportunities.

- The HEC-RTS package continues to advance. HEC-RTS has the ability to integrate flow forecasts from other models through HEC-DSS. It also has the ability to integrate flow forecasts with different computational time steps.

HEC-RTS is designed to report on damages incurred and avoided and life loss predicted and avoided. This is an important capability of this framework

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Quiz

Five Questions

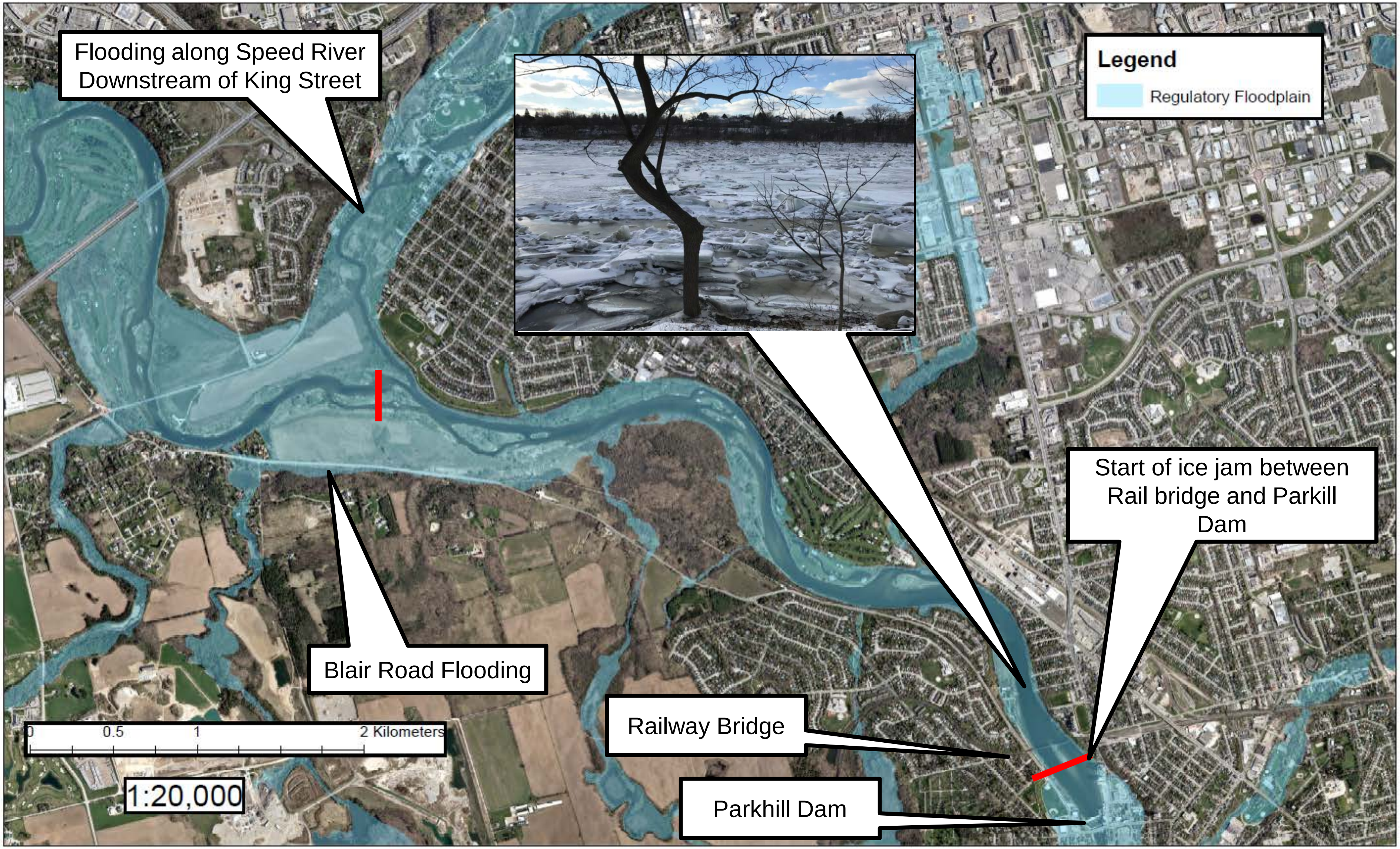
- What are the two high level outcomes ______________ and ____________?
- Floods can be ________________ ?
- Dikes and reservoirs ___________ ?
- Digital Floodplain mapping has ________ purposes ?
- Flood inundation maps provide an __________ of flooding?
- Emergency Prepared Mapping helps reduce _________ in floodplains where development is present ?
- What does RTS mean _______ ?

Five Answer

- What are the two high level outcomes **Reduced Risk to Life** and **Reduced Risk to Life**.
- Floods can be **Managed**.
- Dikes and reservoirs **Reduce the Risk**.
- Digital Floodplain mapping has **Multiple** purposes.
- Flood inundation maps provide an **Estimate** of flooding.
- Emergency Prepared Mapping helps reduce **risk to life in** floodplains where development is present.
- RTS stands for **Real Time System.**

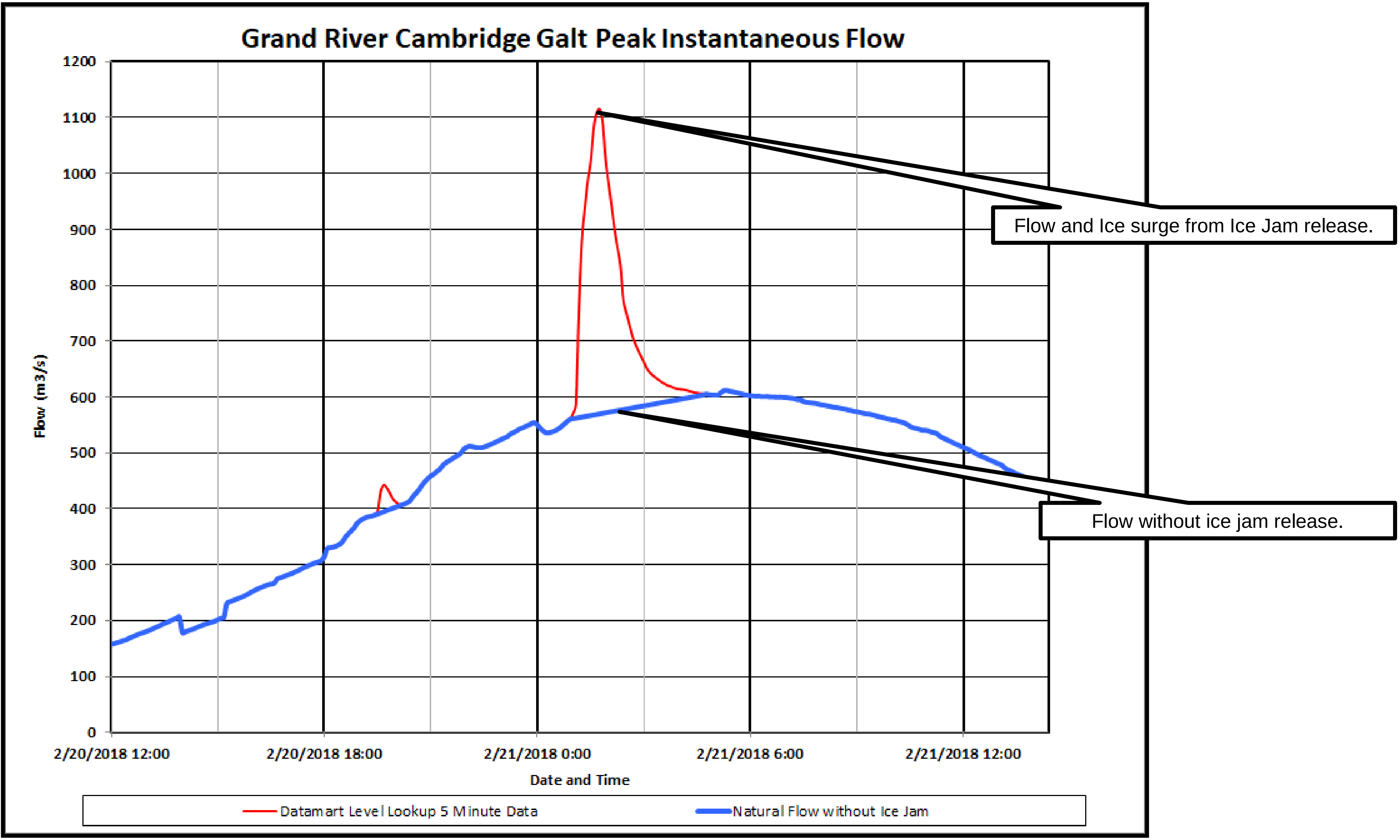
Cambridge Brantford Ice Jams

Ice Jam Location Parkhill Blair Reach

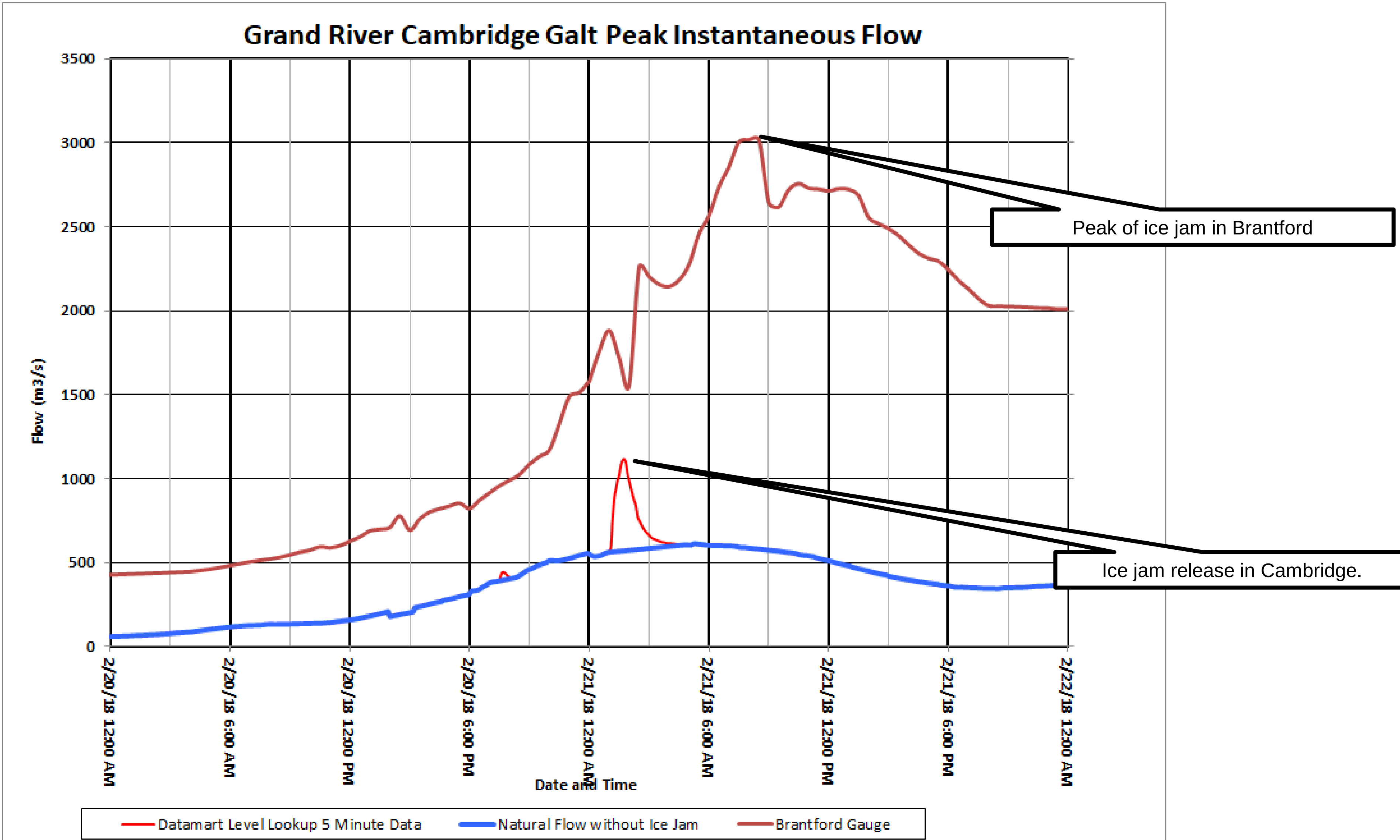


Intact ice upstream of Parkhill Dam stayed in place and resulted in an ice jam.

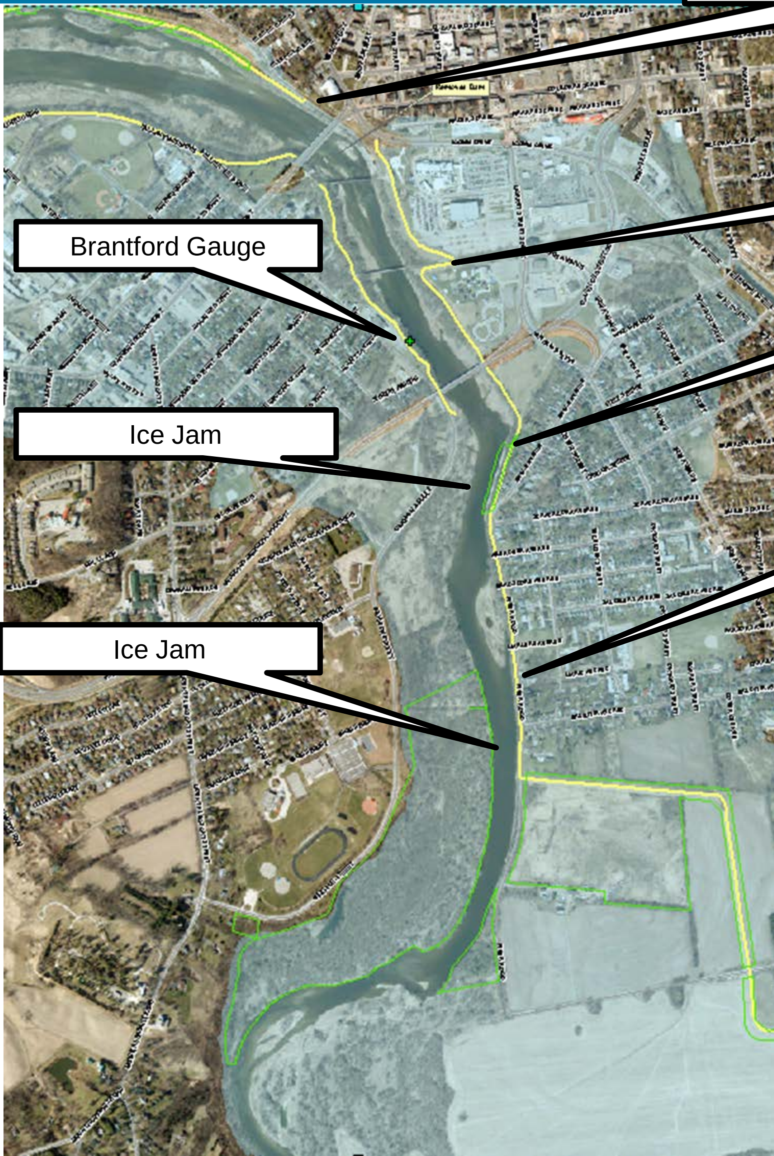
Sudden Release of Ice Jam in Cambridge



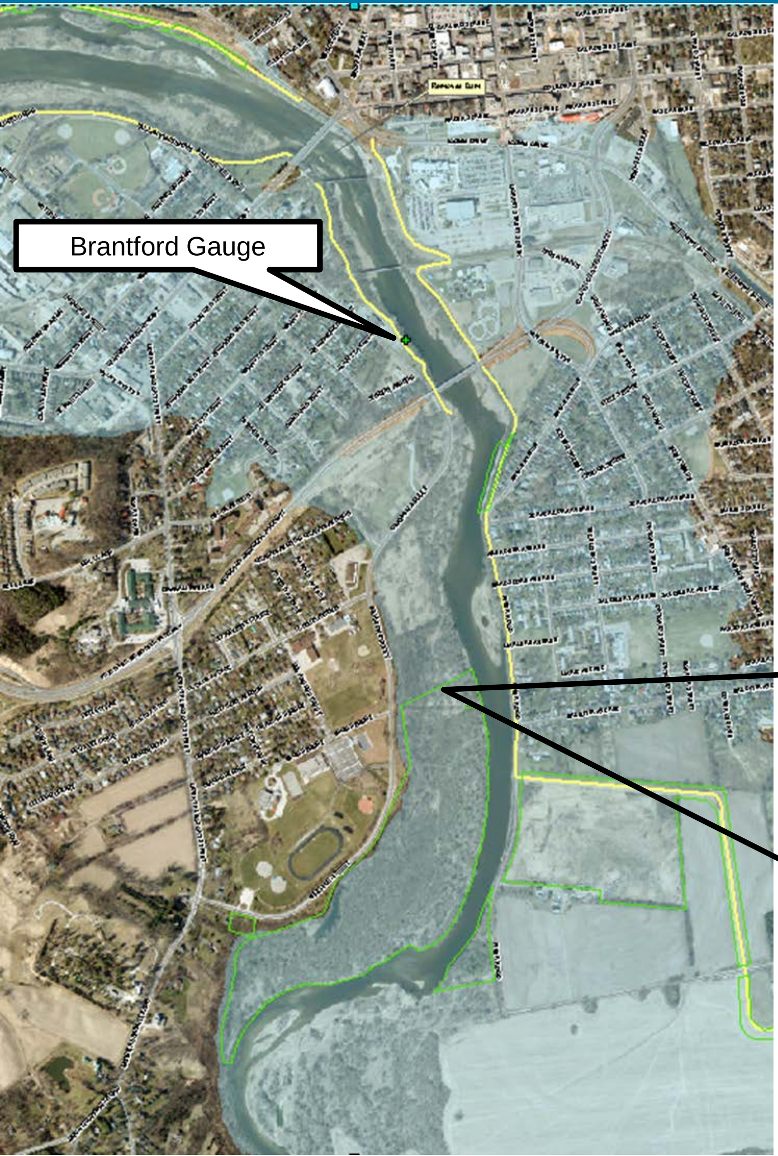
Sudden Release of Ice Jam in Cambridge



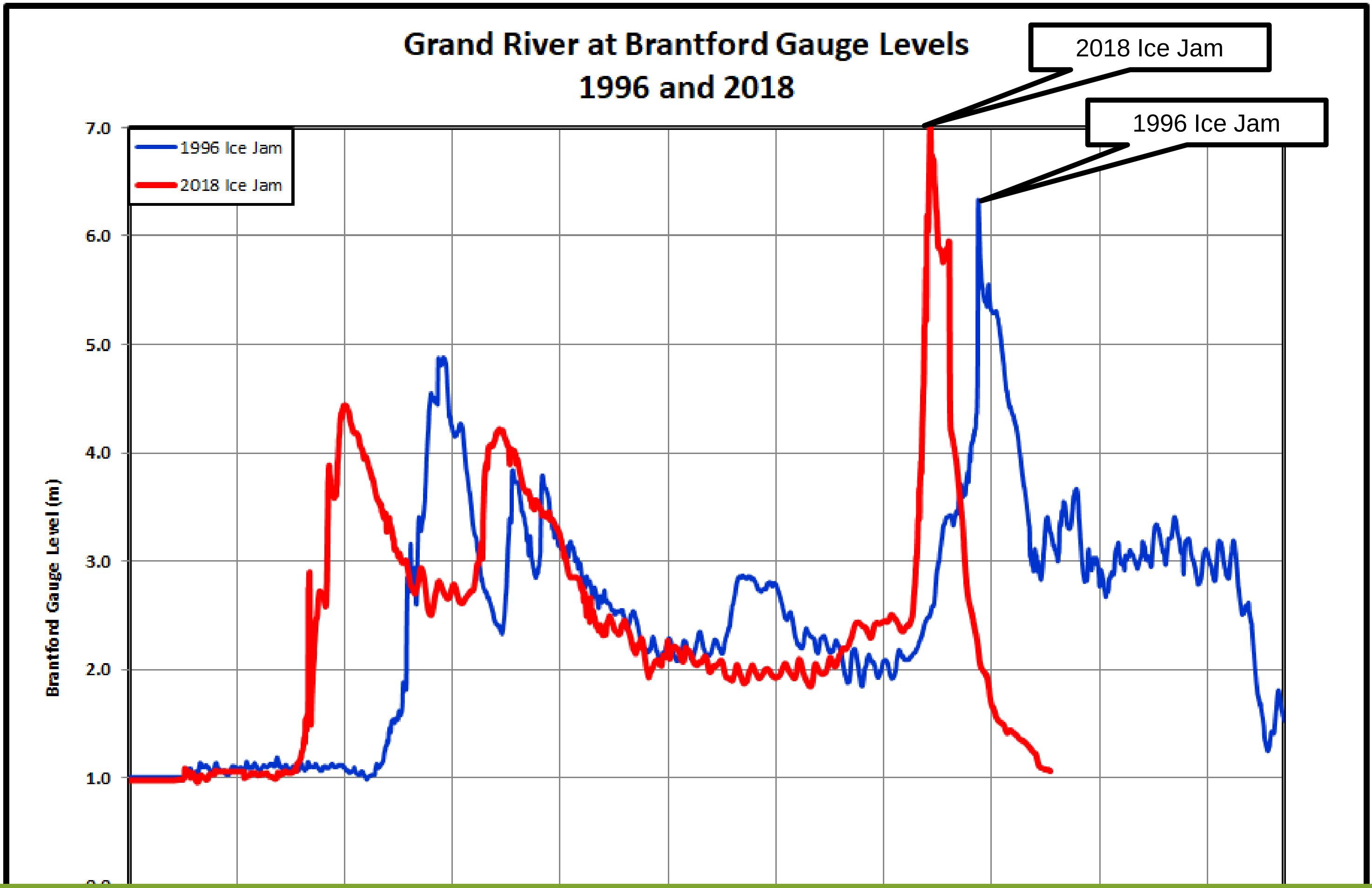
Brantford Dike Reach



Brantford Dike Reach
Potential Future Improved Capacity

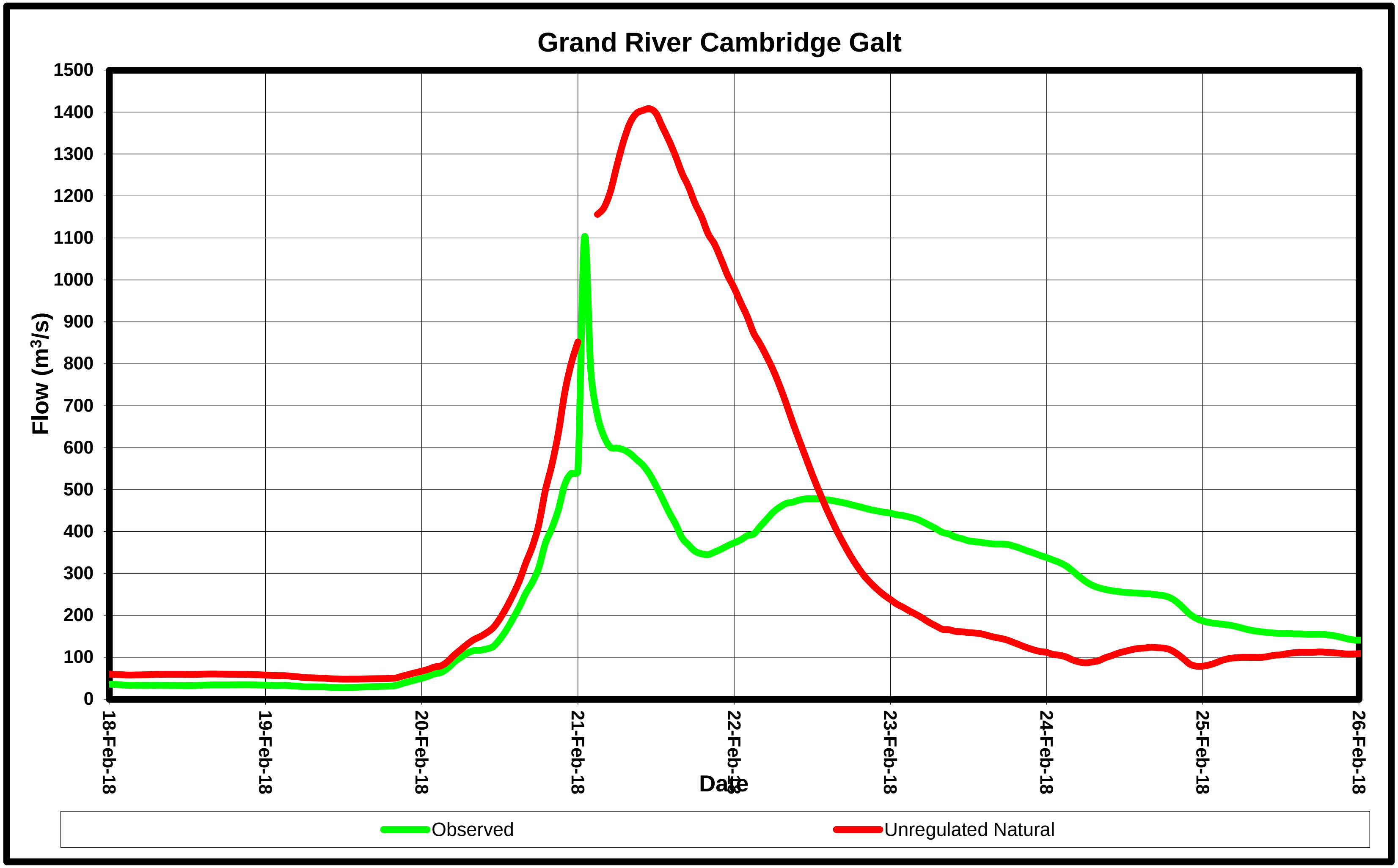


Brantford Stream Gauge Levels 1996 and 2018 Ice Jams

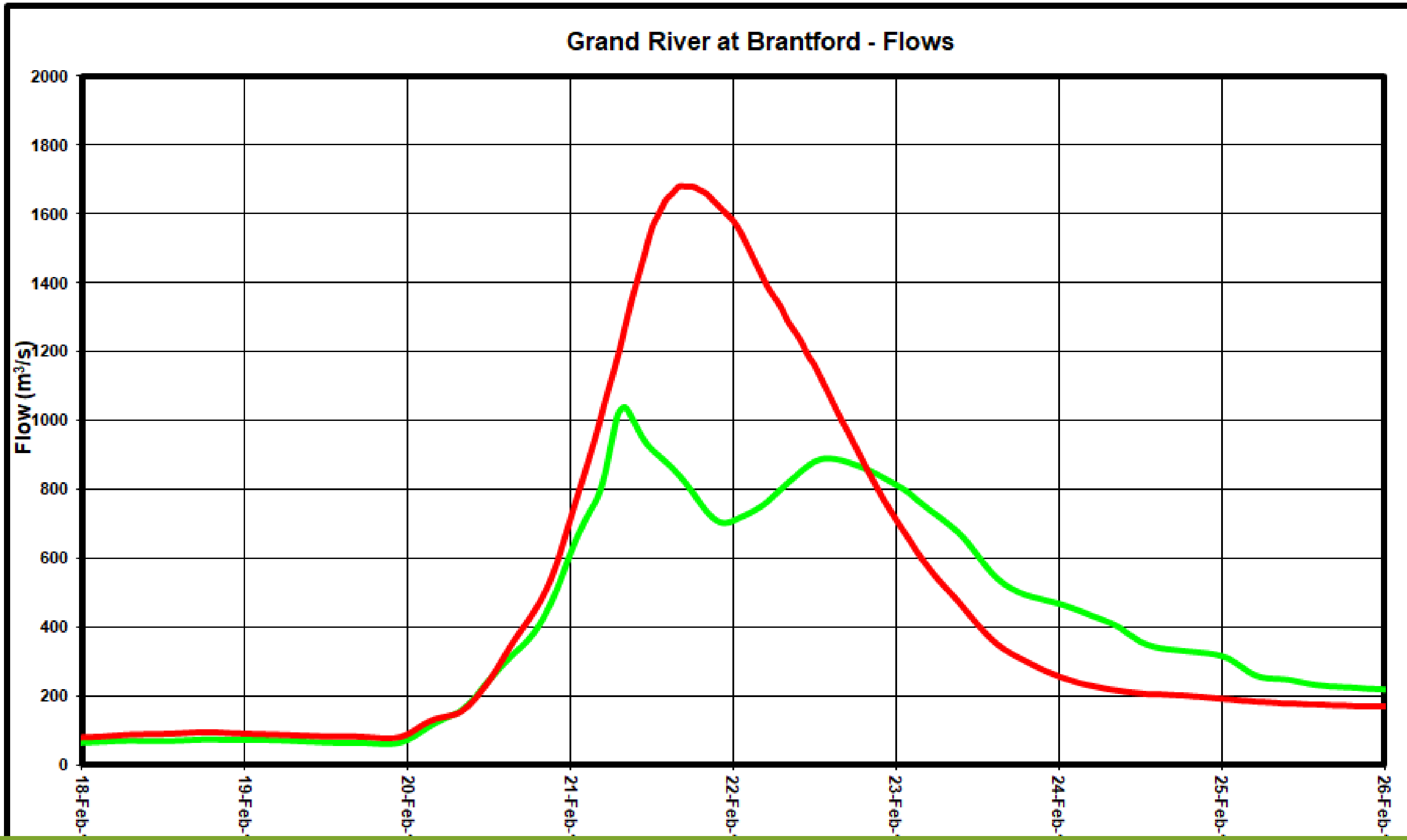


Since about 1990 there have been more early winter melts. These melts are often followed by flash freezes and can trigger breakup ice jams that freeze in place.

Unregulated flood flow through Cambridge

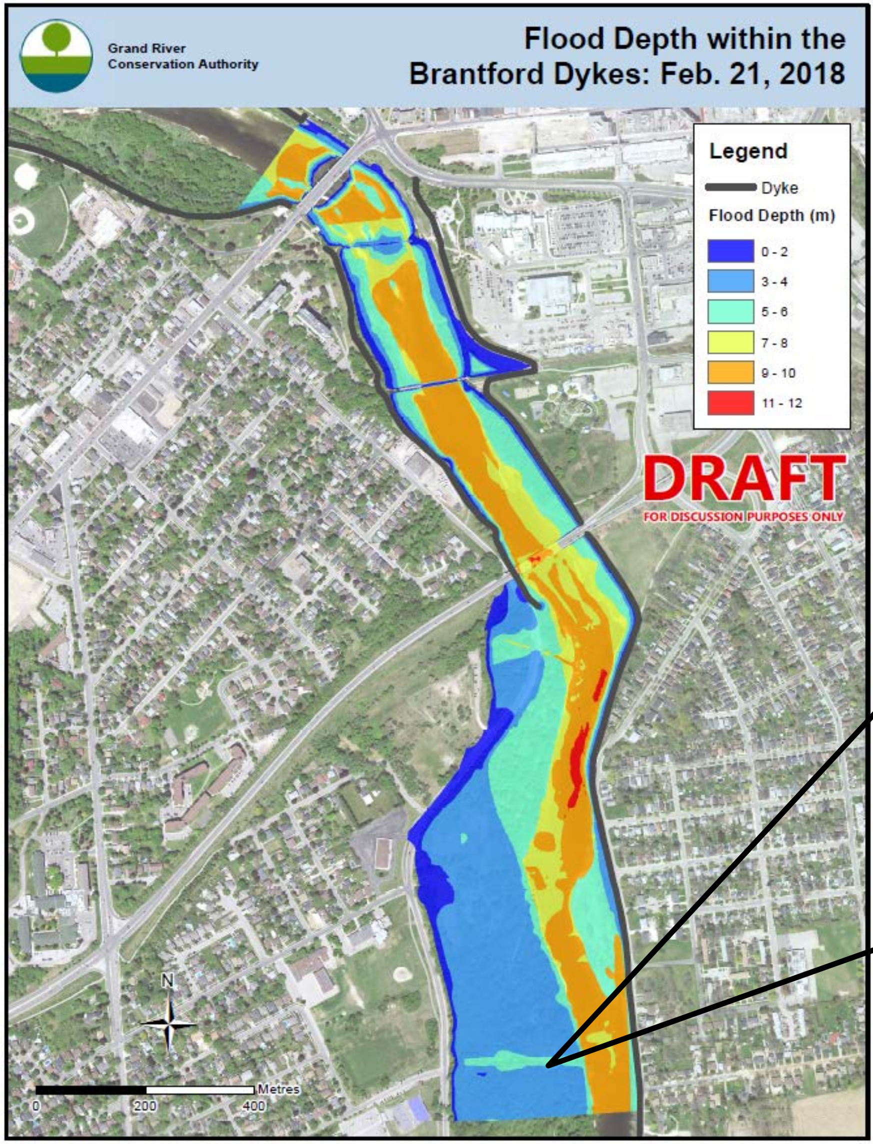


Unregulated flood flow through Brantford



Millions of dollars of flood damages and avoided by flow reduction by upstream reservoirs and protection provided by dikes.

Brantford Dike Reach
Estimated Ice Jam Depth



Field Inspection by Ice Experts

Spyros Beltaos, Ph.D., P.Eng., FCSCE
Research Scientist
Watershed Hydrology and Ecology Research Division, Canada Centre for Inland Waters, Environment & Climate Change Canada

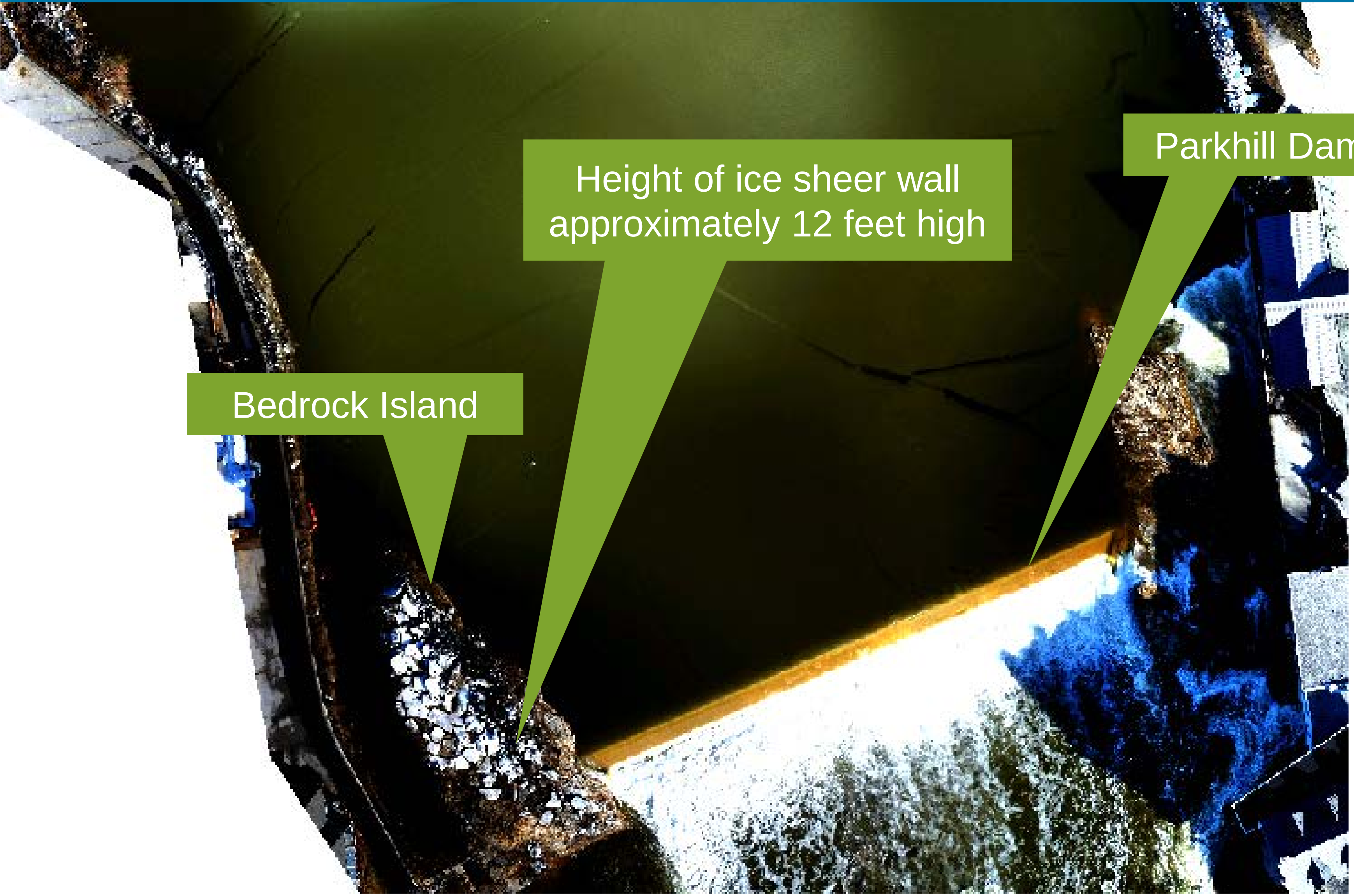
Fuad Curi, P. Eng.
Water Resources Department Head
KGS Group
402 - 4310 Sherwoodtowne Blvd.
Mississauga, ON, L4Z 4C4
(905) 848 7884
(905) 848 2473
Fax: (905) 848 9664
www.kgsgroup.com

UAV Mapping Cambridge Ice Jam

Jean-Francois Dionne, GISP, C.Tech
UAS/UAV Technical Survey Specialist
UKKO a Division of Ag Business and Crop Inc.
Eastern Canada senseFly Distributor
Cell: (519)292-9585
Office: (613)722-2605
jfdionne@ukkocanada.ca
www.ukkocanada.ca

- UAV flights were performed by UKKO Canada one week after the ice jam.
- 5 cm orthoimagery and point clouds were obtained for a 5 km reach upstream of the Parkhill Dam in Cambridge were obtained
- The photography will be used to complete forensic analysis of the ice jam and ice dam that setup upstream of Parkhill Dam.
- Ice experts will be engaged to used this mapping to help explain the breakup event

UAV Mapping Cambridge Ice Jam



UAV Mapping Cambridge Ice Jam Example of Imagery Detail

UAV Mapping Cambridge Ice Jam Example of Ice Scrapping Landscape

Questions
We learn from every flood!