Flood Forecasting During Major Flood Events: The 2011 Manitoba Flooding Experience

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Banff, Alberta
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Contents

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1 Introduction

Definition

Flood: an overflow or inundation of water from a river or other body of water which causes or threatens loss of life and property and environmental damage.

The severity and frequency of flooding is influenced by:

- Extreme rainfall
- High temperatures causing fast snow melt
- High temperatures causing ice break-up
- Storms with high winds
- High soil moisture conditions
- High river/ lake levels
- Ice jams – especially during winter mild spells and spring thaw
- Windchill conditions that produce significant frazil ice, which is slush consisting of ice crystals that form in water that is too turbulent to freeze over

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Definition

Flood Forecasting: The use of real-time and or future meteorological and hydrological data in precipitation-runoff and streamflow routing models to forecast flow rates and water levels for periods ranging from a few hours to days ahead.

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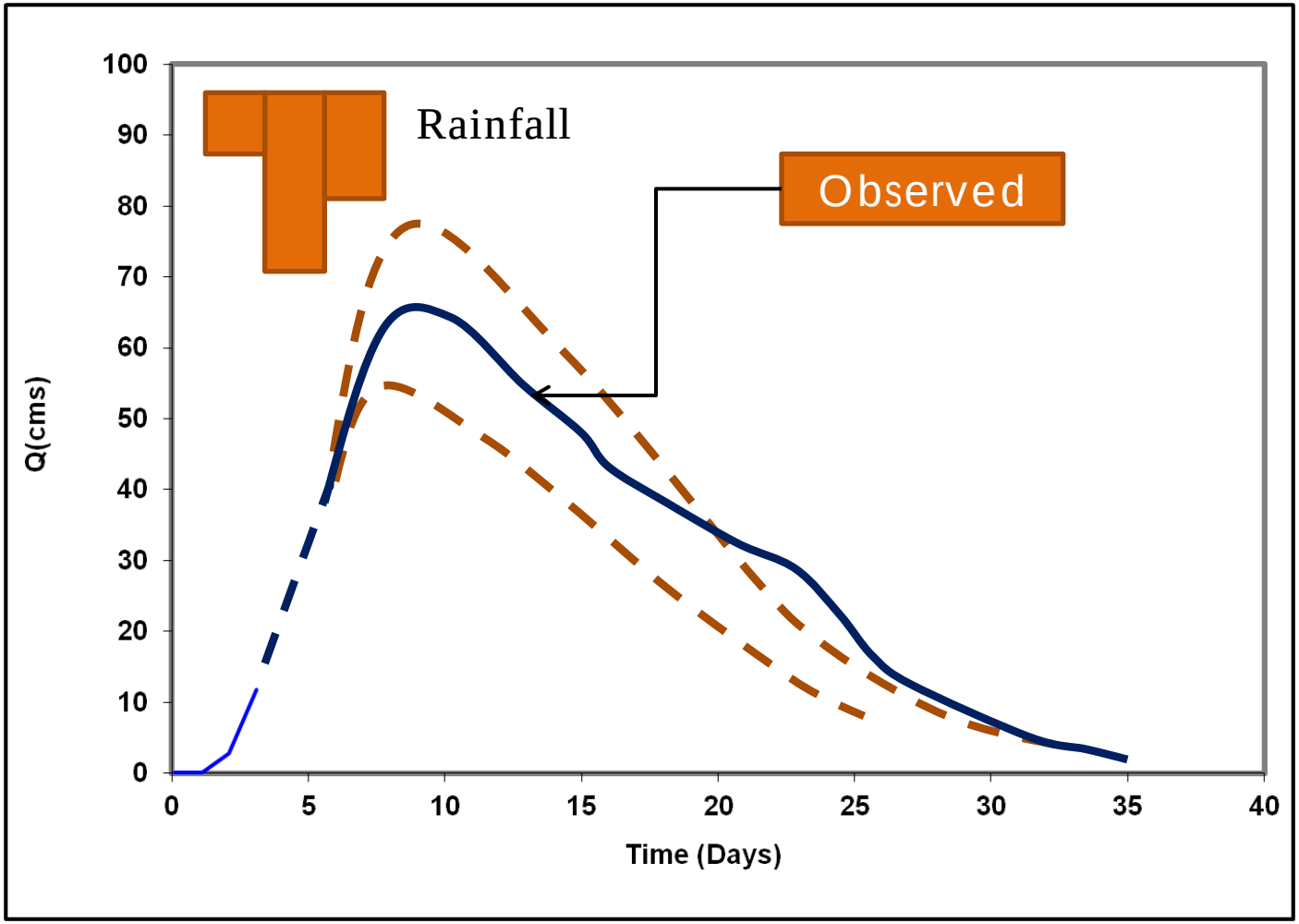
2 Forecasting: The Science, Art & Chaos



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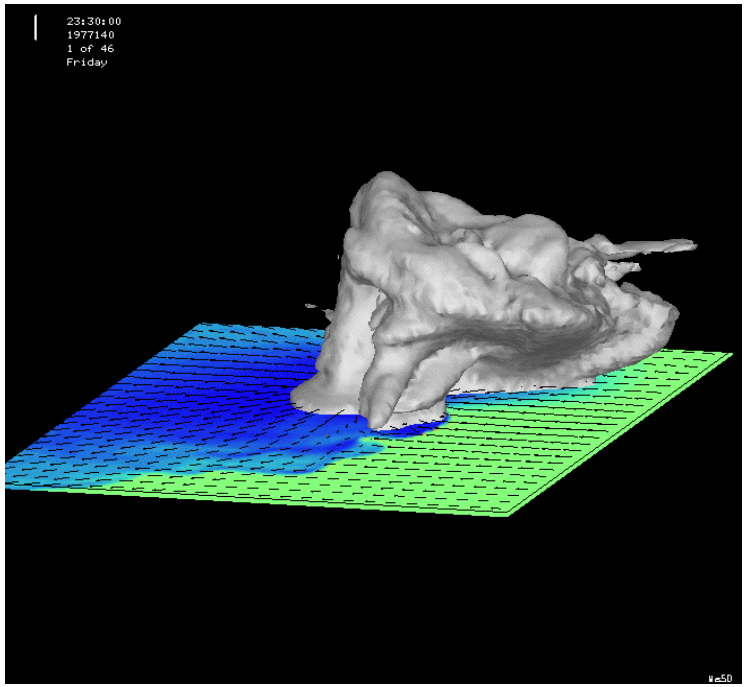
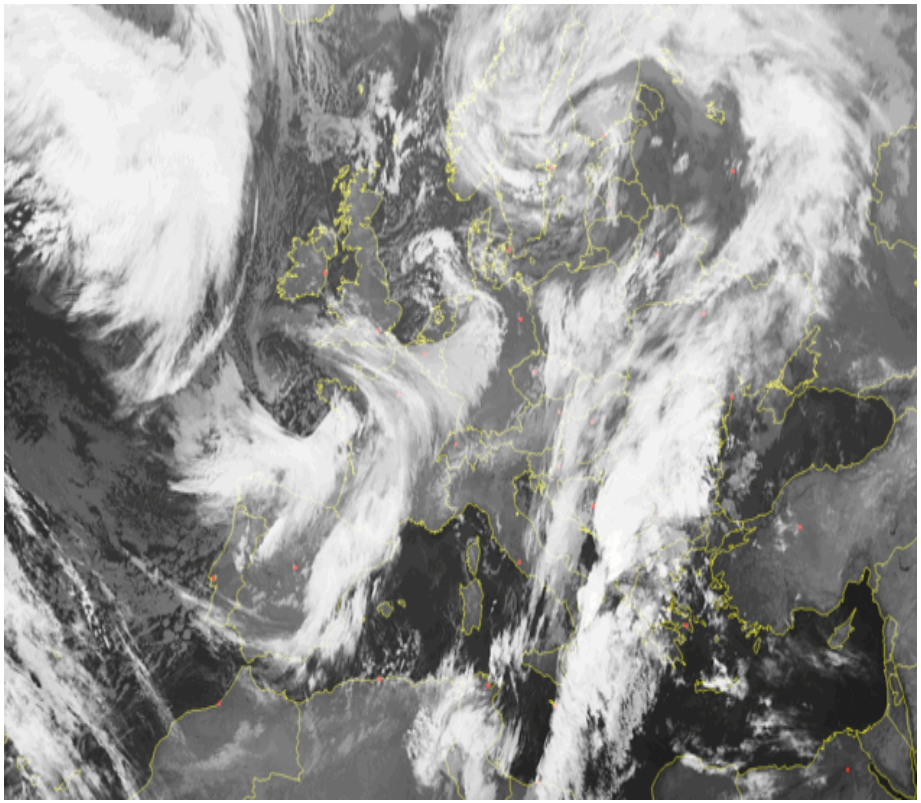
Dealing with more predictable systems to less predictable systems

- Occurrences of extreme hydro-climatic phenomena are complex and chaotic with random and deterministic components.





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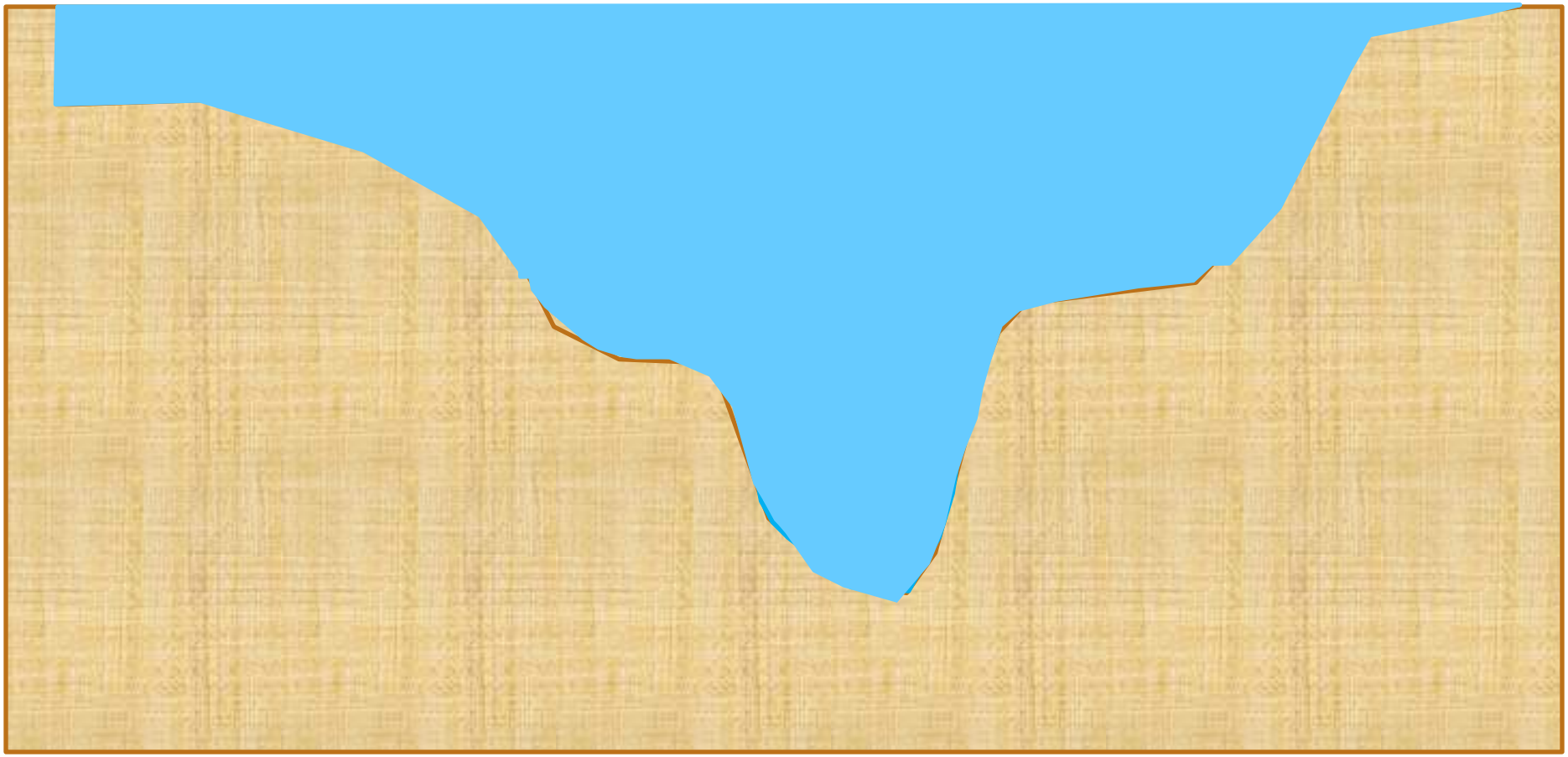
1-D & 2-D Flow Regimes



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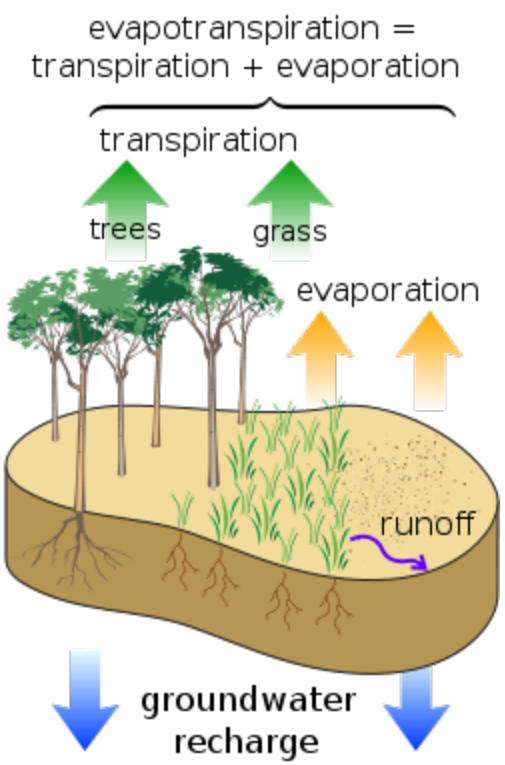
How do we deal with these complex systems in flood forecasting ?
Use Various Types of Flood (Hydrologic) Models



Water Cycle

- Stochastic: Empirical—simple linear empirical to highly complex statistical models
- Deterministic (process-based): Accounts for bio-physical processes responsible for generating runoff from precipitation
- Lumped: Does not account for spatial variability
- Distributed: Accounts for spatial variability
- Event-based or continuous

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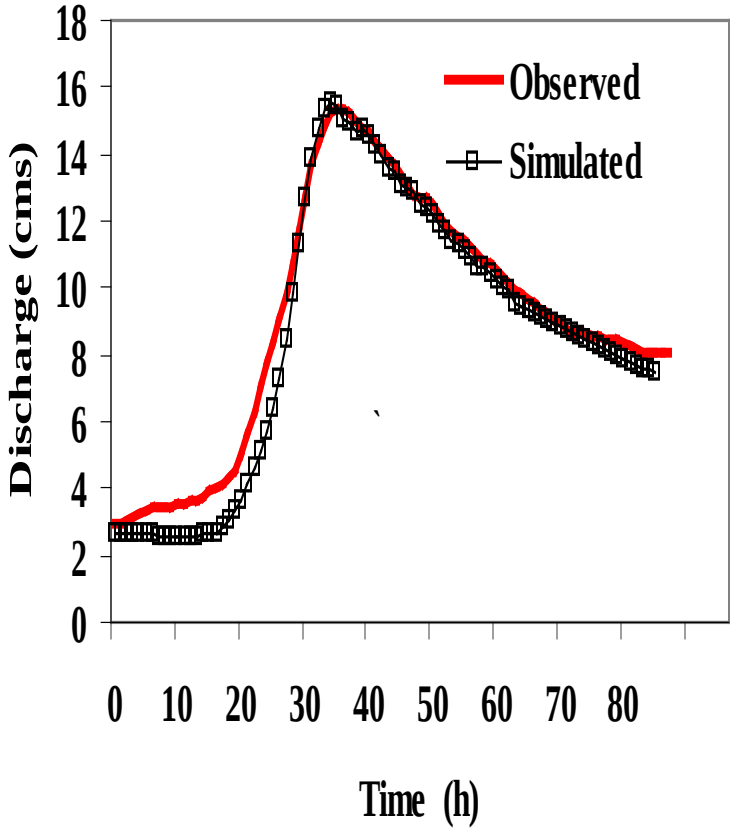
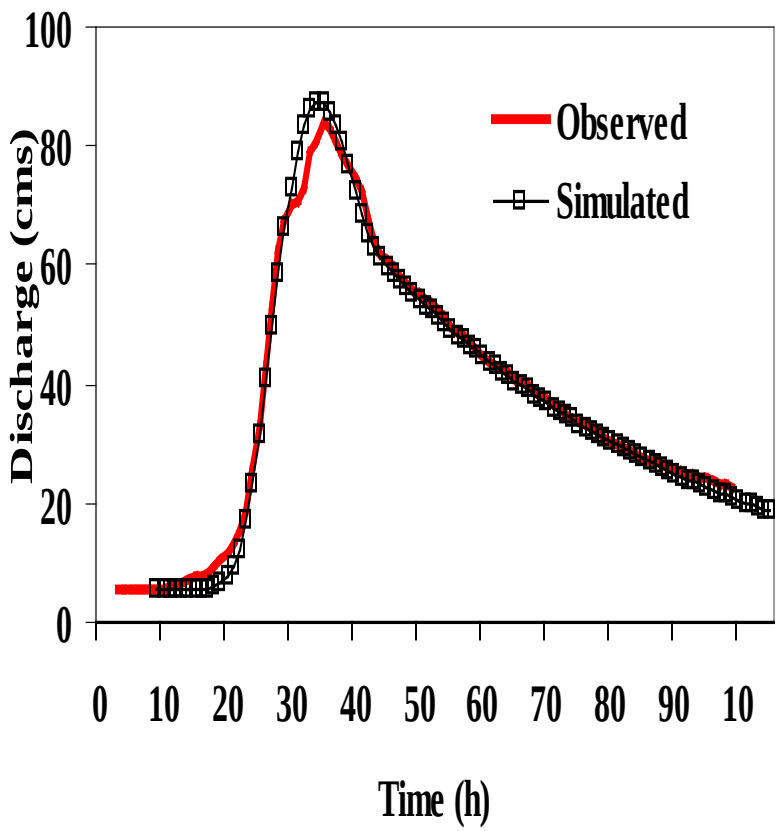
Calibration & Model Validation Process





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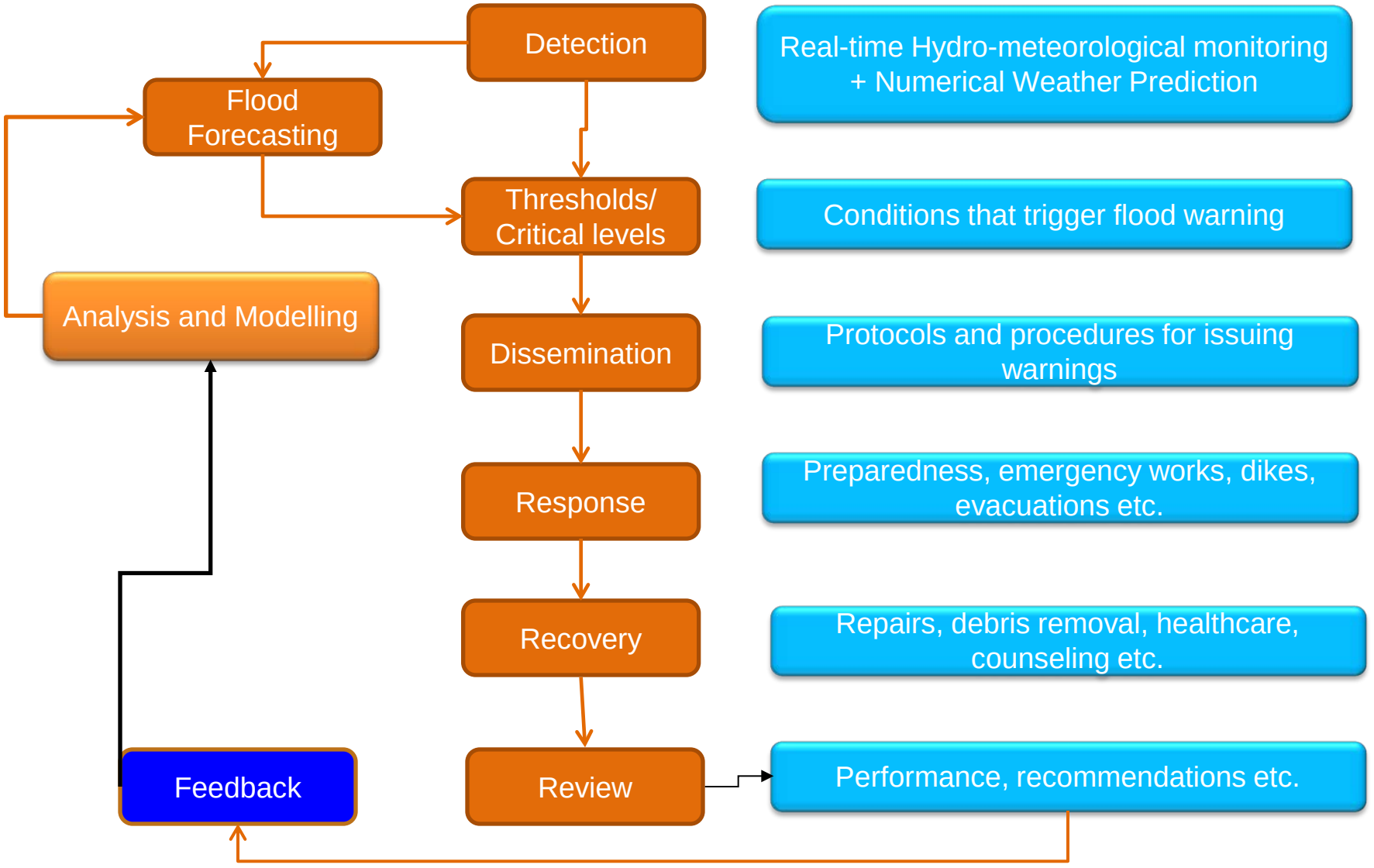
3 Forecasting, Warning and Emergency Response System



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4 A Look at the 2011 Manitoba Flood

Preamble

What led to 2011 Manitoba flood ?

- High soil moisture level (saturated soils)-elevated baseflow/ groundwater levels (prior to freeze-up time)
- High river or lake levels (prior to freeze-up time)
- Strong winds over water bodies
- Heavy winter snow pack
- Ice jams (not so significant in 2011)
- Rapid snow melt (temperature) – turned out to be favourable
- Additional heavy spring/ summer storms on already saturated soils, especially over the Assiniboine and the Souris river as well as Interlake regions

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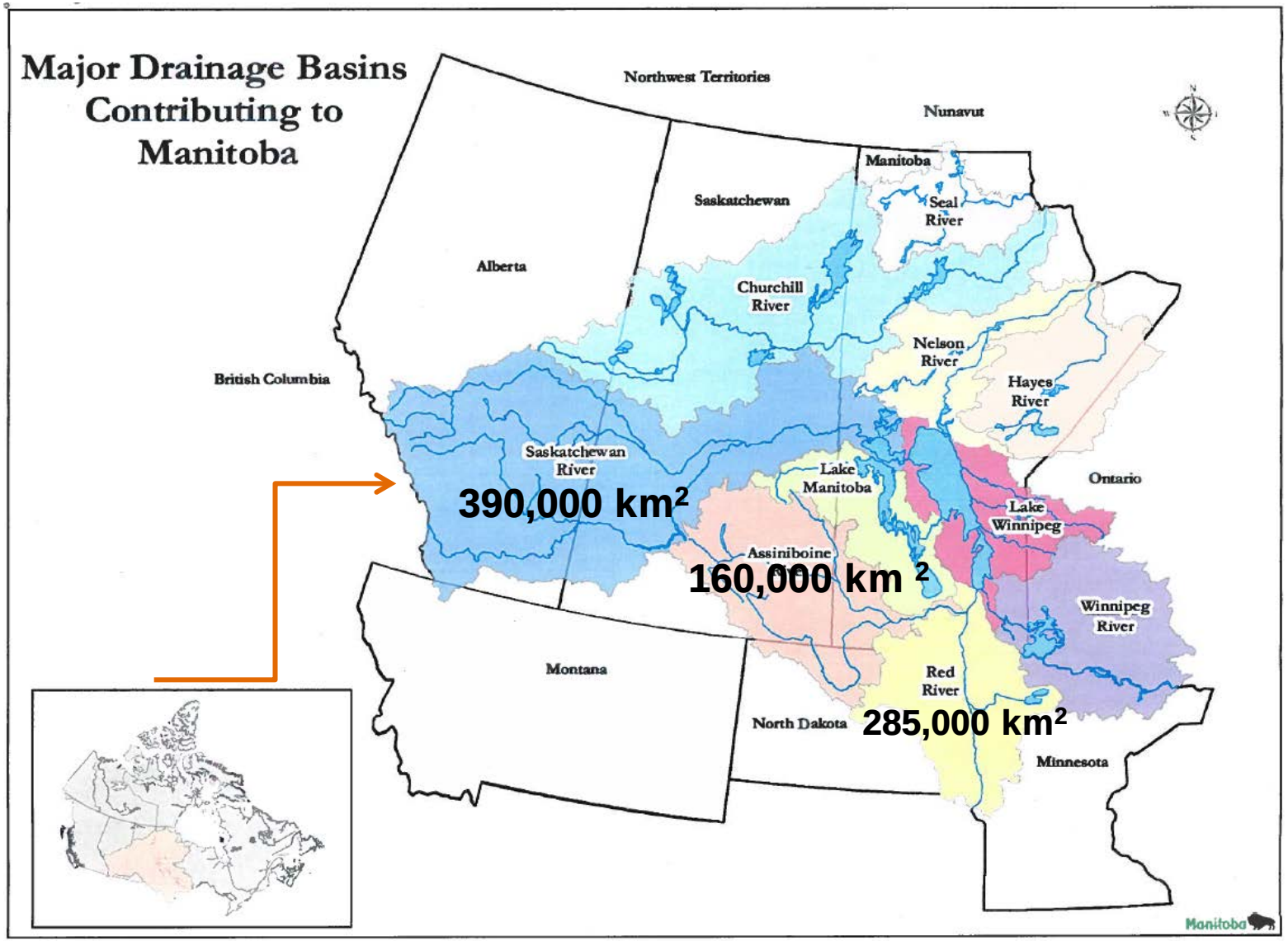
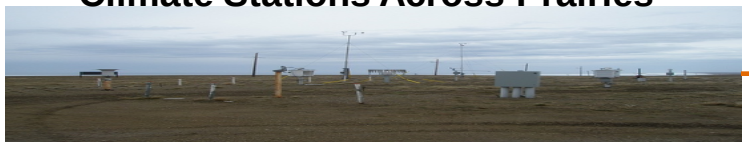
Watersheds


Major Drainage Basins Contributing to Manitoba
Northwest Territories
Nunavut
Manitoba
Saskatchewan
Seal River
Alberta
Churchill River
Nelson River
British Columbia
Hayes River
Saskatchewan River
390,000 km²
Lake Manitoba
Ontario
Lake Winnipeg
Assiniboine
160,000 km ²
Winnipeg River
Montana
Red River
North Dakota
285,000 km²
Minnesota
Manitoba

2010 Pre-Freeze-up Preparations

Tracking May-October Rainfall & Soil Moisture Conditions

Climate Stations Across Prairies



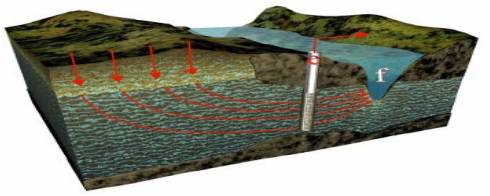
Special Aircraft (Soil moisture – Gamma Surveys)

Field Soil Moisture

Flood Forecasting Centre

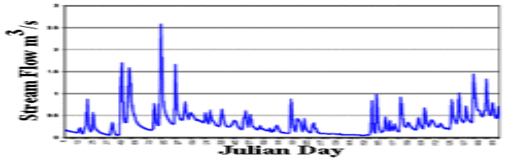
Modelled Soil Moisture: VIC Model

Groundwater Levels



Hydrometric Data

River/ Lake levels



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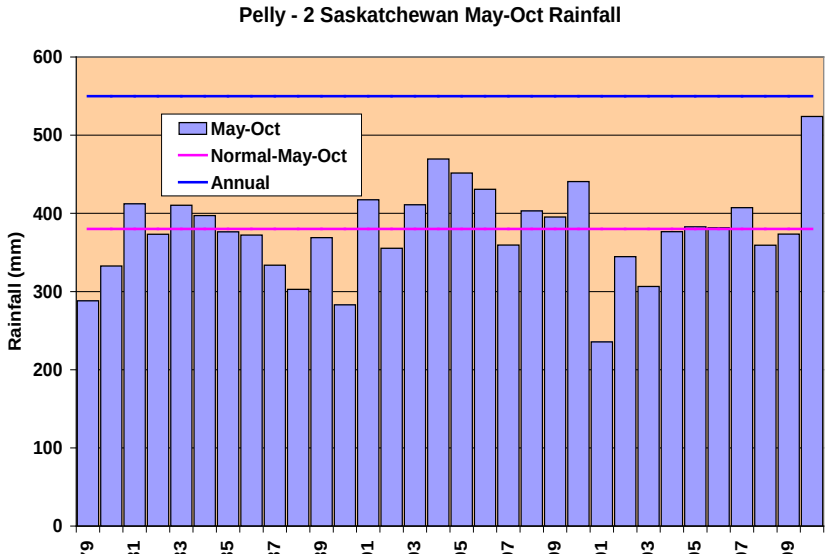
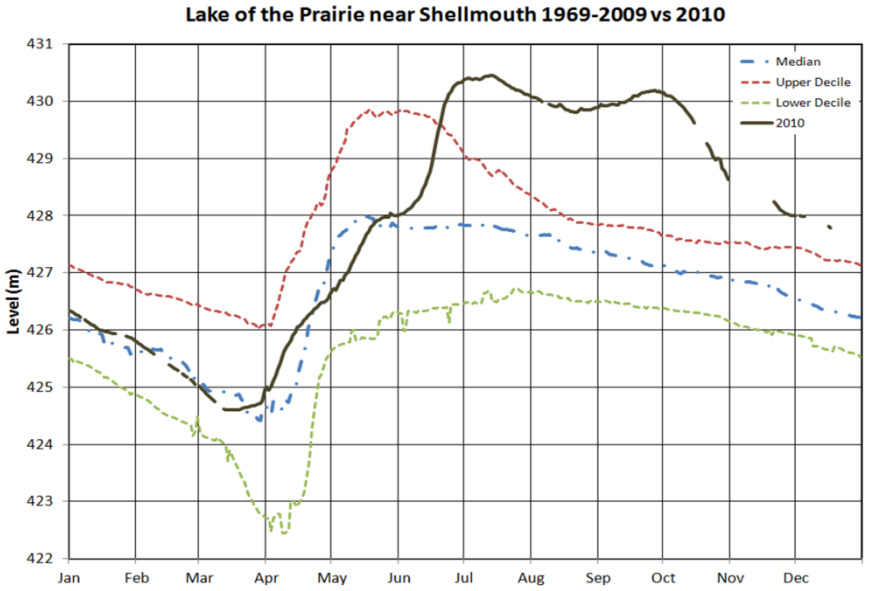
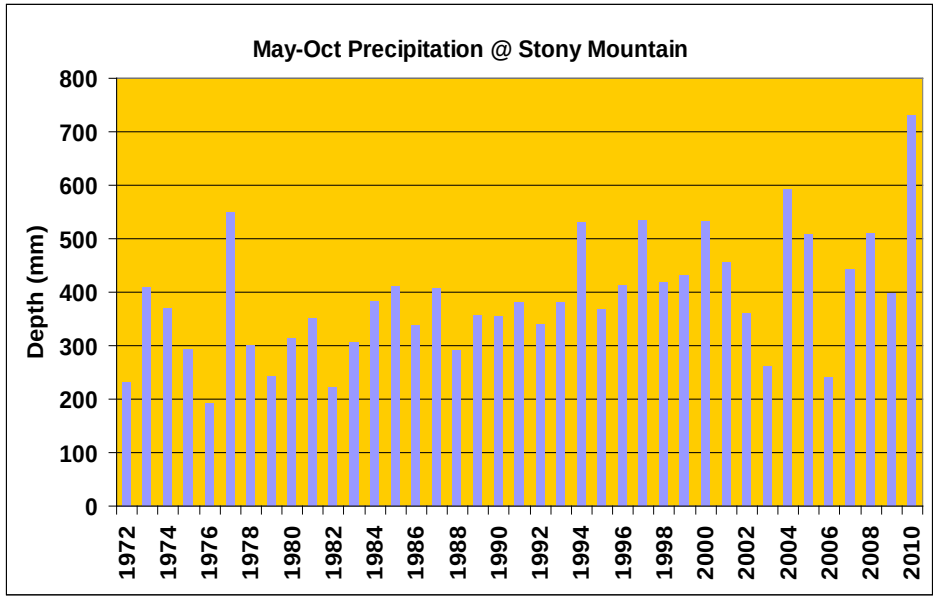
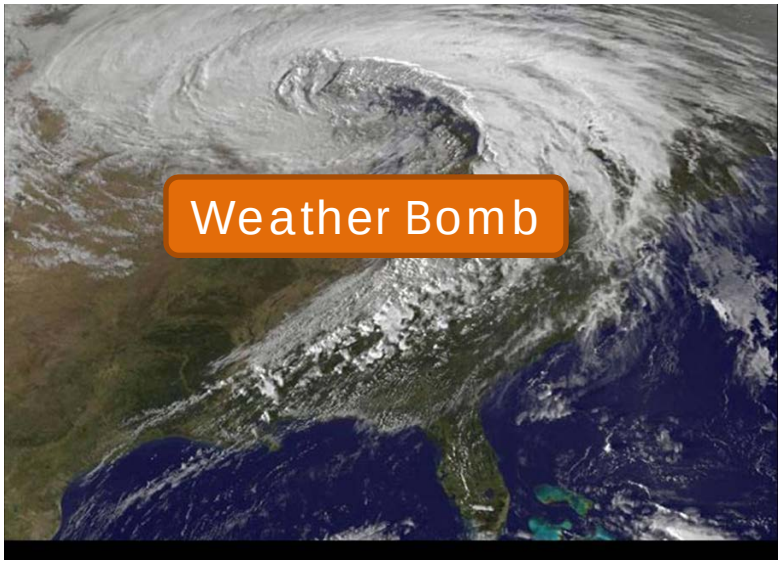
Shellmouth Reservoir Flood 2010/11 – Conditions

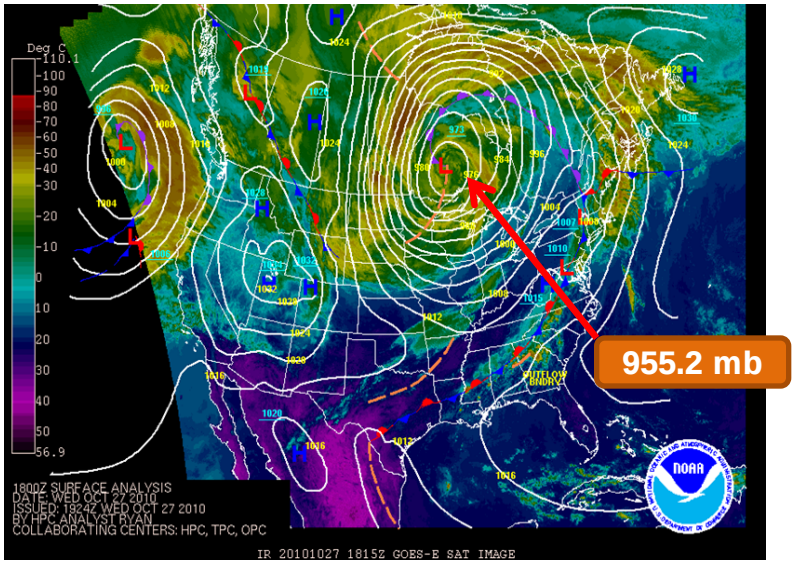


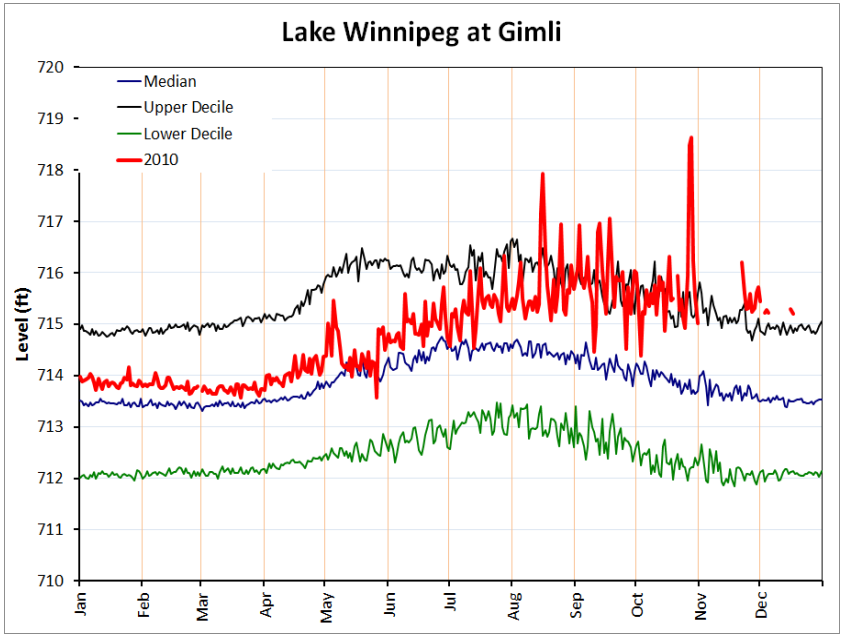


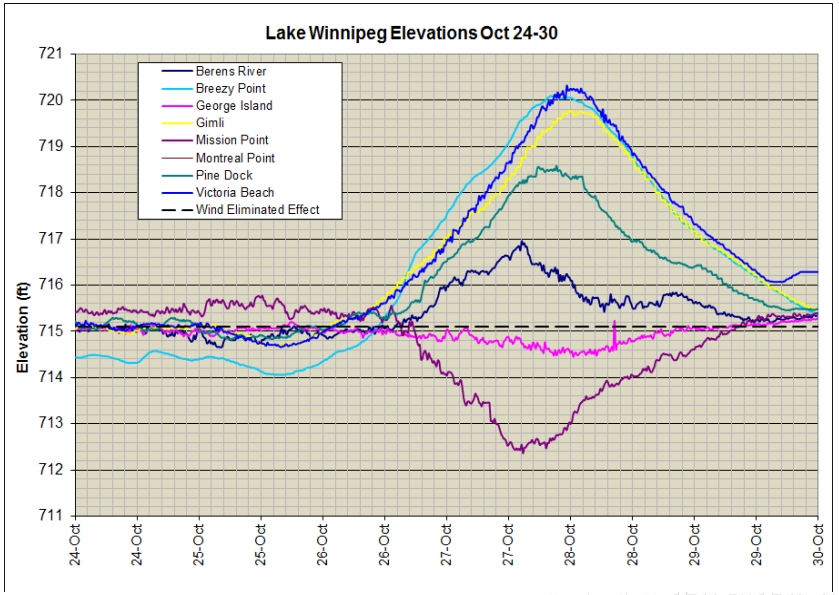


Antecedent Extreme Weather System in 2010
October 26-28, 2010









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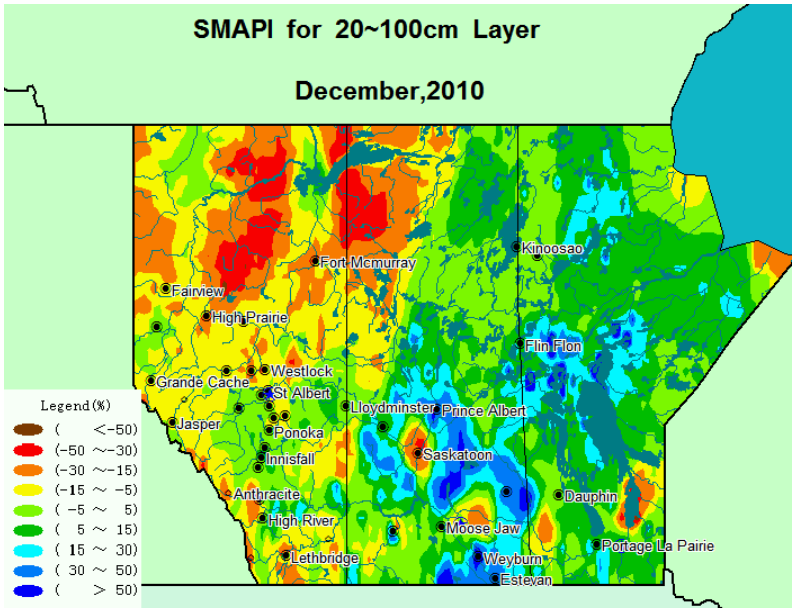
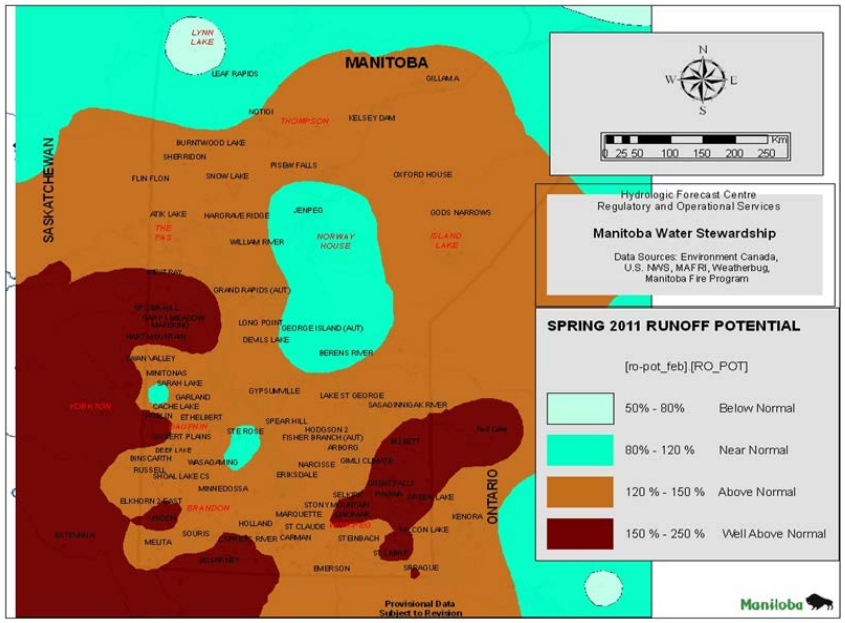
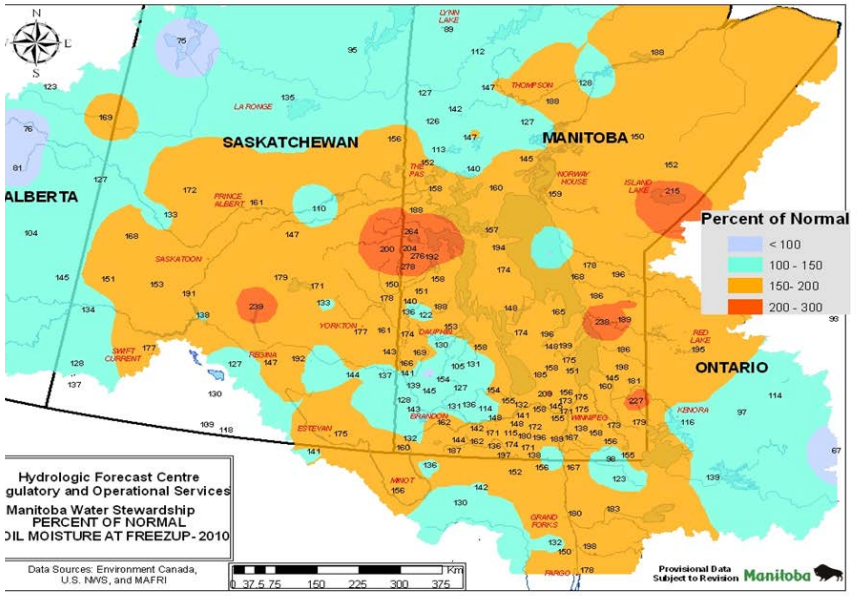
Wet 2010- Fall/Autumn Across the Province

Above normal rainfall from in spring to autumn 2010 led to above normal soil moisture conditions across the province and the Nelson Basin as a whole





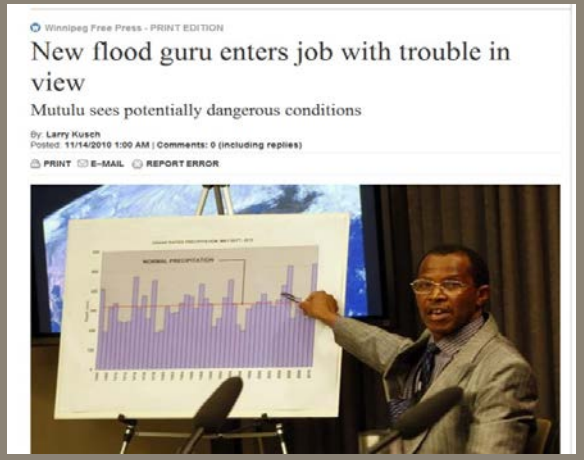


Early Pre-Cursor Signals

•Nov 14, 2010 preliminary spring outloof called for potentially significant conditions flooding across the province

- High soil moisture level (saturated soils)
- High ground water levels
- High river or lake levels

➢ If combined with heavy precipitation, rapid snowmelt/ significant rains, would spell dire conditions for flooding


Winnipeg Free Press - PRINT EDITION

New flood guru enters job with trouble in view

Mutulu sees potentially dangerous conditions

By: Larry Kusch
Posted: 11/14/2010 1:00 AM | Comments: 0 (including replies)

PRINT E-MAIL REPORT ERROR

- Winter 2010 started with heavy snowfall
- Concerns for flooding increased
- Unusually early springflood outlook issued in January 2011
- In collaboration with Emergency Measures Organization the Flood Forecast Centre Director started visiting different communities to provide early warning information
- Further outlooks provided in February and March 2011 still calling for significant flooding across most major watershed

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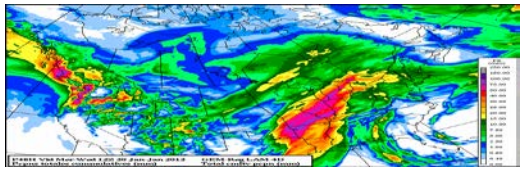
Dealing with Multiple Sources of Data/ Databases

Numerical weather forecast



Satellite data

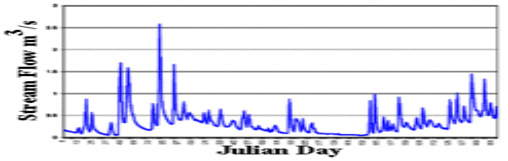
Weather Radar

Weather Stations

Special Aircraft (Snow-Gamma Surveys)

Flood Forecasting Centre

Upstream river flow forecasts



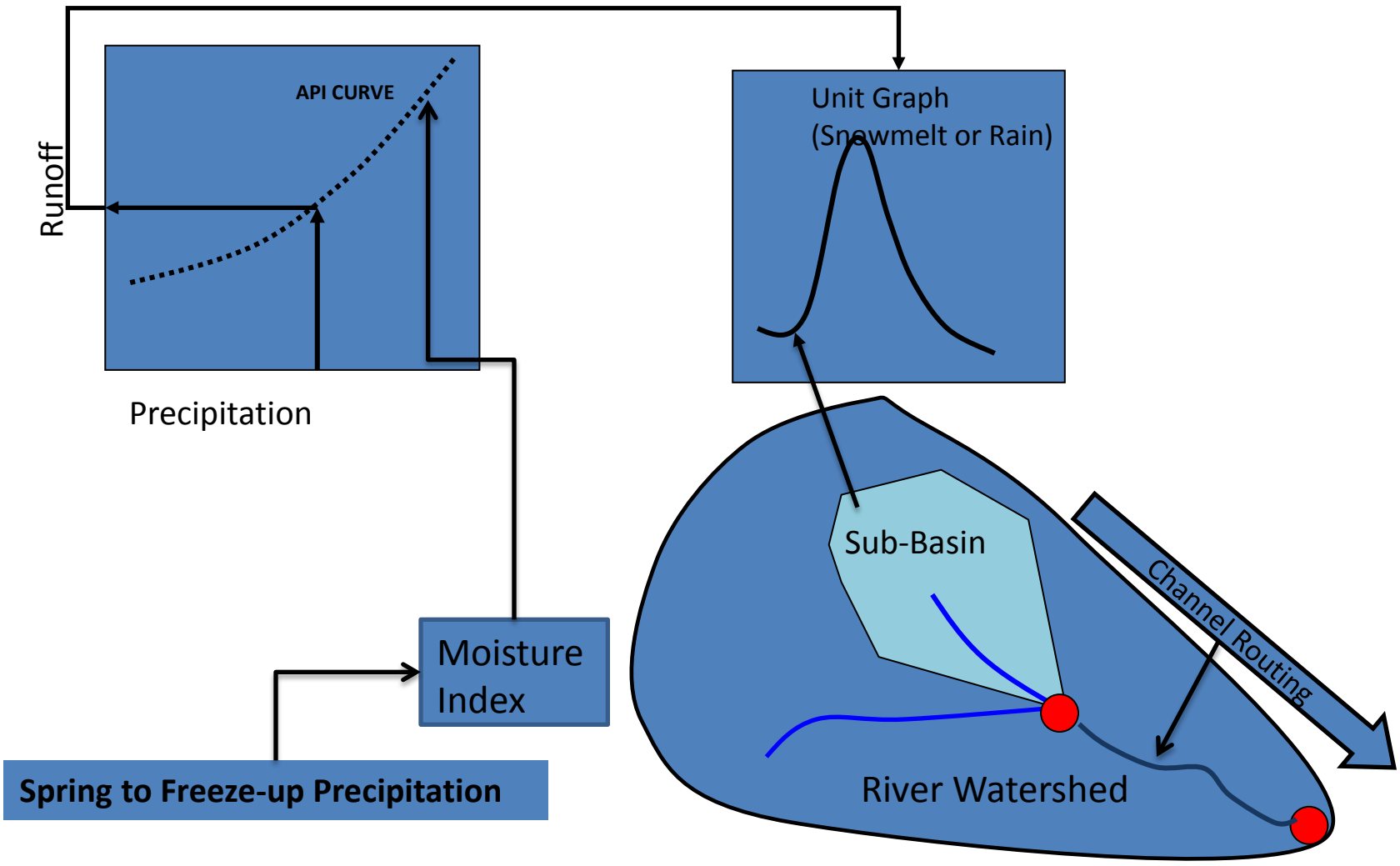
Automatic river gauges

- Depth of soil frost
- Ice-thickness in water bodies

Field snow pack measurements

Water level & flow metering

Methodologies



Simplified Schematic View of the River Flow Forecasting Model (Event Based Approach)

Methodologies: Operational

- Manitoba Antecedent Precipitation Index (MANAPI)

  Runoff = f(SMI,PRECIP [Snow+Rain])

  - Unit Graph + Muskingum routing for major rivers
  - Unit Graph + Linear reservoir storage routing based on various numerical schemes, including Runge Kutta 4th order scheme
- Natural Resources Soil Conservation Runoff Curve Number (NRSCN) for excess rain computation adopted during 2011 flood
- Analog approaches: Looking back at similar hydrologic conditions
- Regression-based methodologies
- 2-D flood modelling for complex studies; flood compensation, etc. (applied later for post flood analyses)

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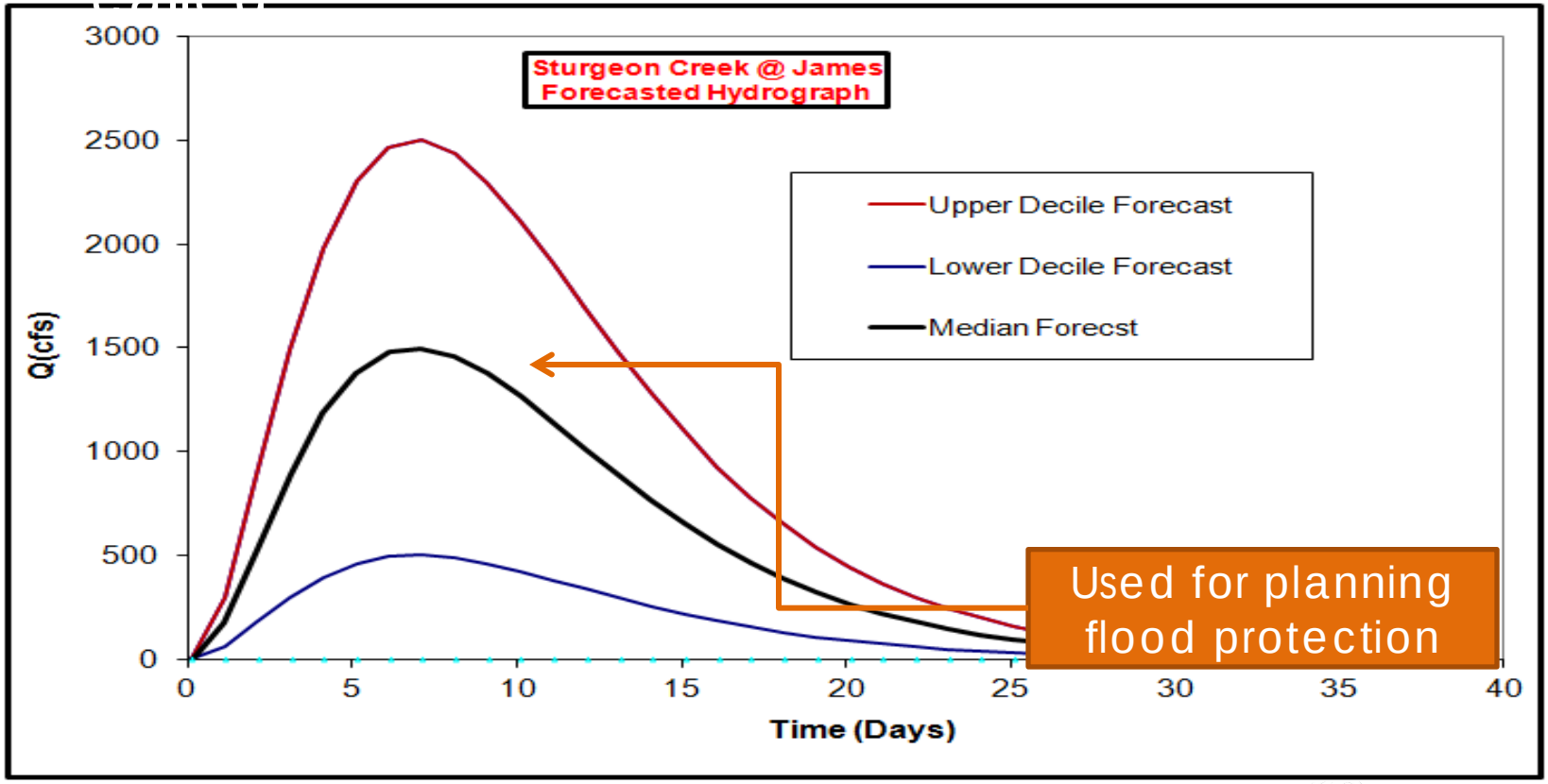
Methodologies: Factoring in Uncertainties

Use of upper decile (unfavourable), median, and lower decile (favourable) margins in model inputs

- e.g. upper decile soil moisture and precipitation inputs.



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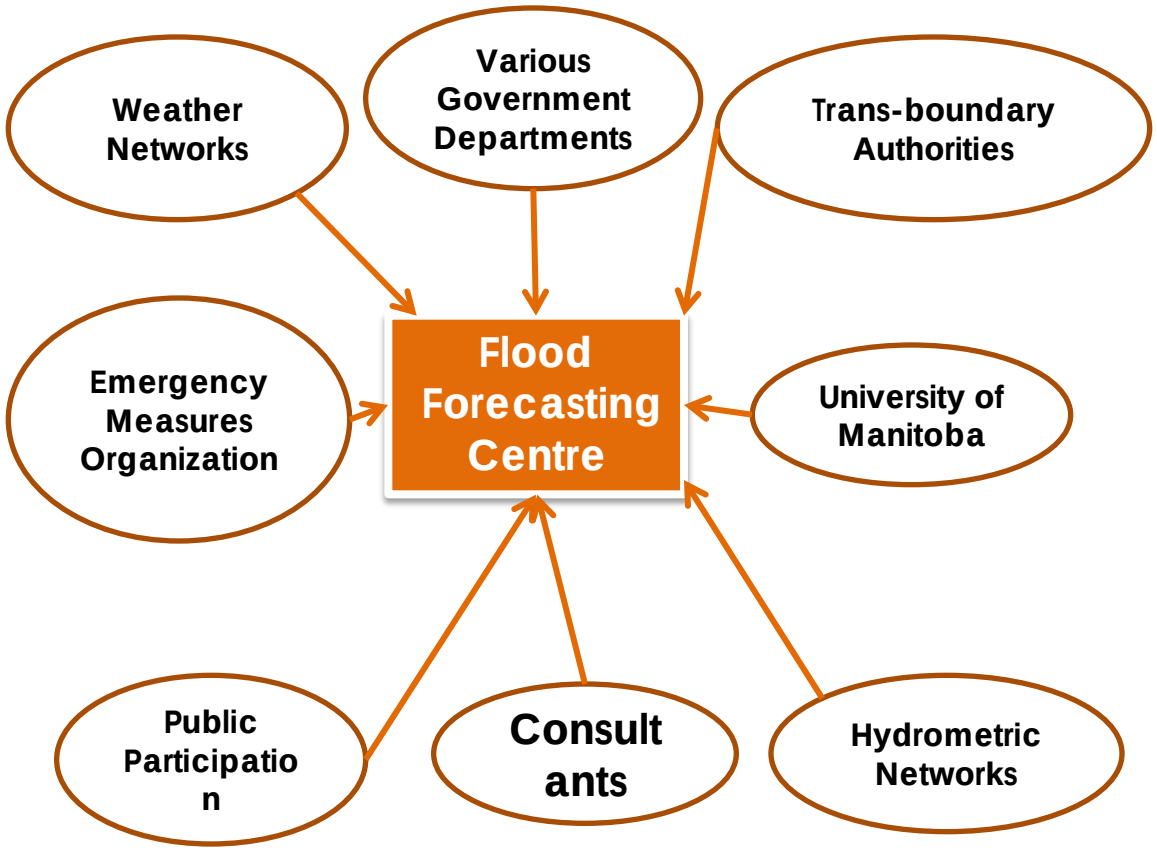
A Collaborative Effort



Disseminating/Exch-ange Flood Information

- Web Publishing
- Fax
- Telephone
- Emails
- Radio
- TV
- EMO

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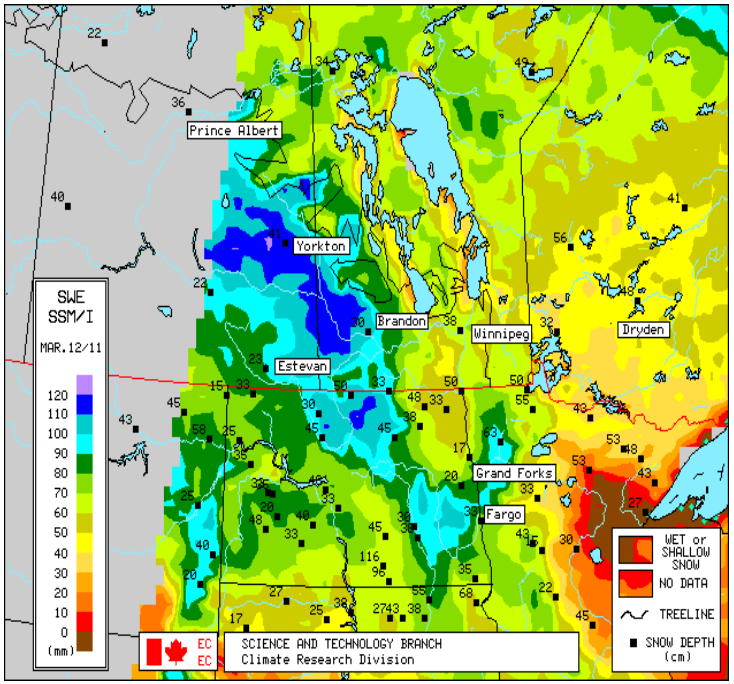
Unprecedented Circumstances

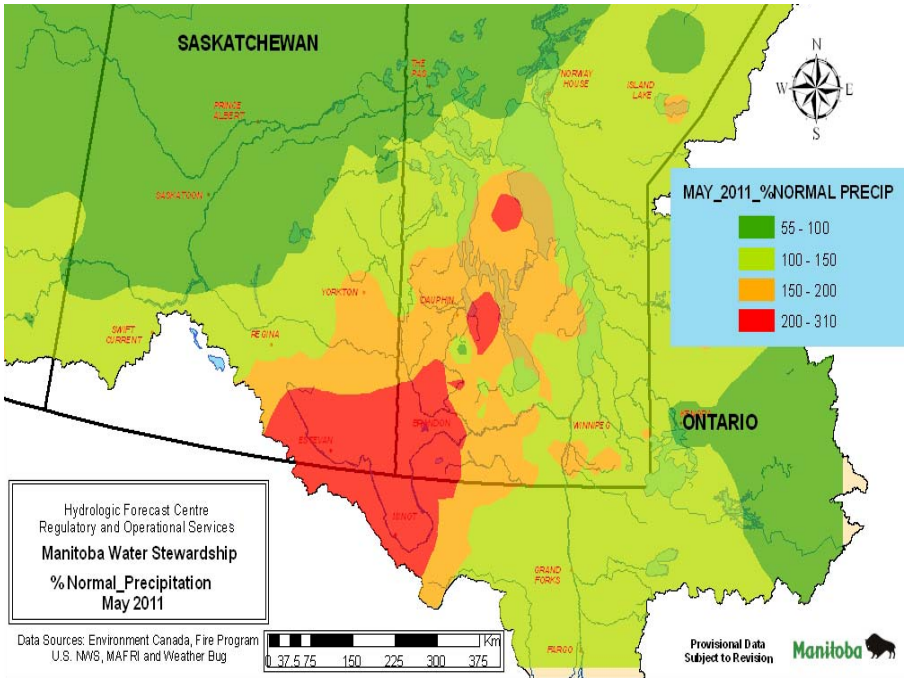
- 2011 Flood: Unlike any other in Manitoba's recent history
- Existing models not calibrated to capture these unseen levels (models are developed based on existing historical data)
- Floods widespread over the province; record water levels; pushing the capacity of forecasting tools, human resources, observation network, and understanding of the prairie hydrology.
- Rating curves were overtopped; estimation of flows and of stages for predicted peak flows was difficult . Hence uncertified in measured discharges due to difficulties measuring under these conditions.

Unprecedented Circumstances

- Limited resources (data gathering, data transmission, etc.)
- Not enough staff; models developed on the fly. Staff working throughout day and night continuously for nearly six months.
- Difficulties were overcome by pulling resources together with tireless collaboration from the private sector and government departments

Sustained Unprecedented Weather Conditions





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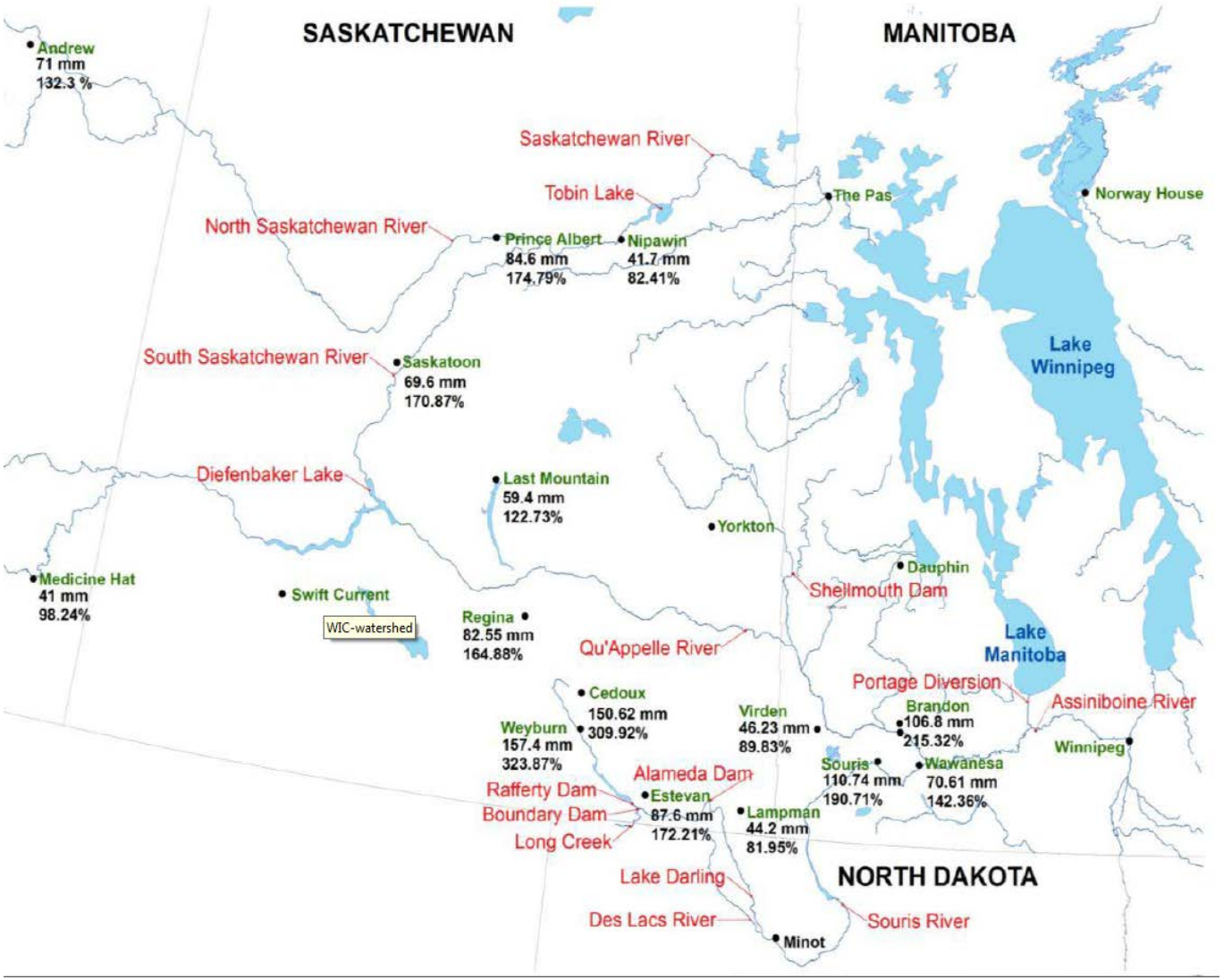
June 2011 Precipitation (mm) and Percent of Normal (%)



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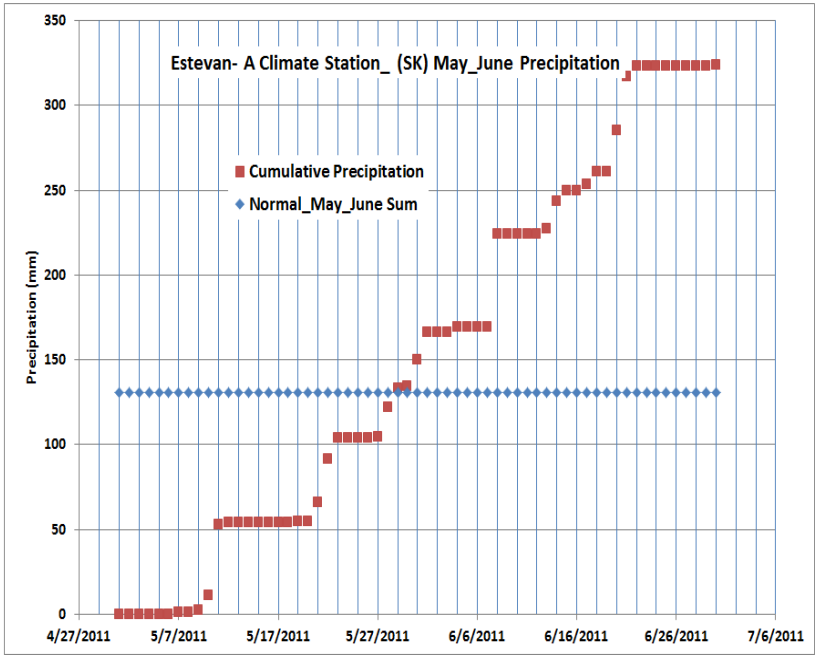
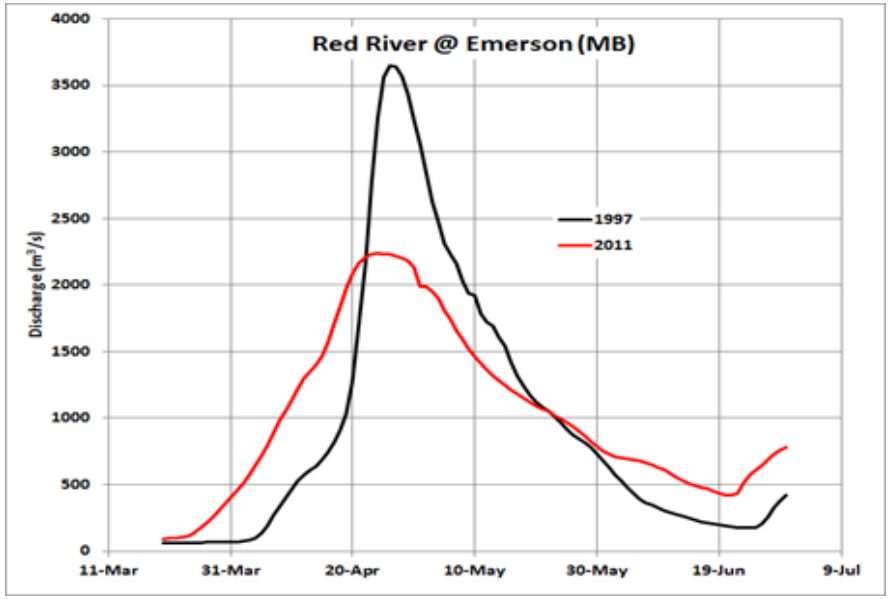
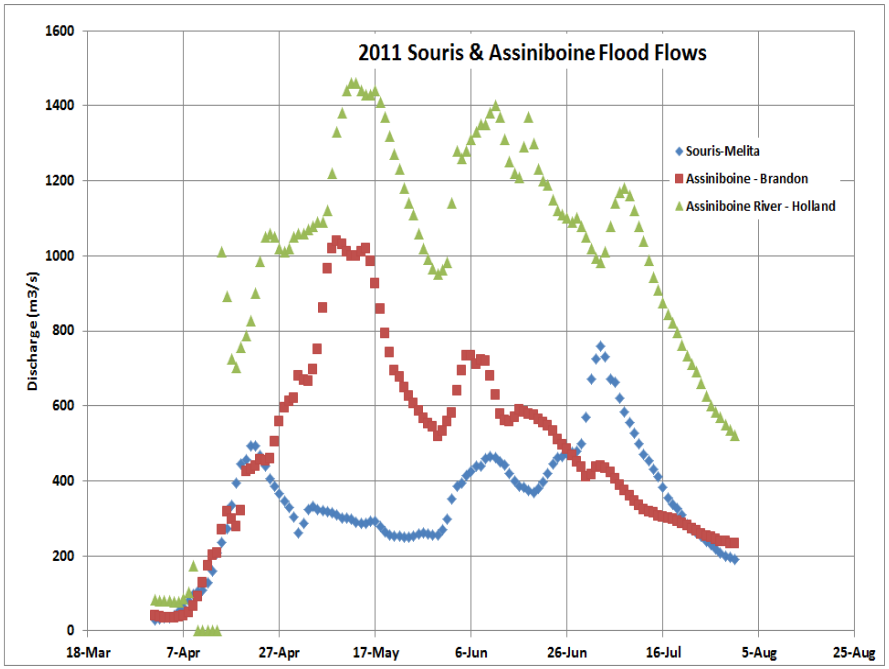
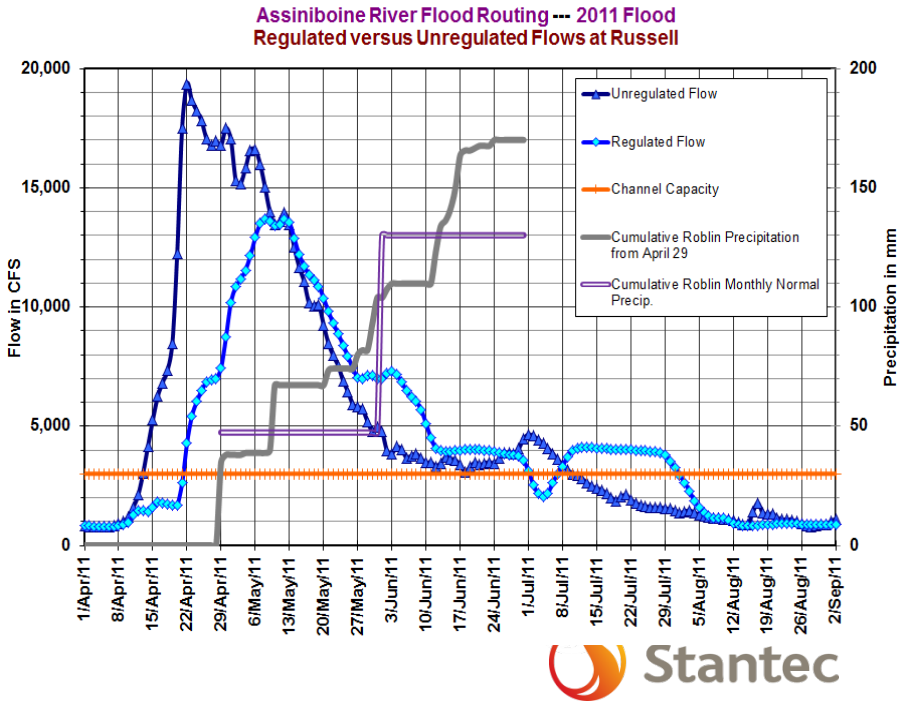

Estevan- A Climate Station_ (SK) May_June Precipitation
Cumulative Precipitation
Normal_May_June Sum
Precipitation (mm)
350
300
250
200
150
100
50
0
4/27/2011
5/7/2011
5/17/2011
5/27/2011
6/6/2011
6/16/2011
6/26/2011
7/6/2011


Red River @ Emerson (MB)
1997
2011
Discharge (m³/s)
4000
3500
3000
2500
2000
1500
1000
500
0
11-Mar
31-Mar
20-Apr
10-May
30-May
19-Jun
9-Jul


2011 Souris & Assiniboine Flood Flows
Souris-Melita
Assiniboine - Brandon
Assiniboine River - Holland
Discharge (m3/s)
1600
1400
1200
1000
800
600
400
200
0
18-Mar
7-Apr
27-Apr
17-May
6-Jun
26-Jun
16-Jul
5-Aug
25-Aug


Assiniboine River Flood Routing --- 2011 Flood
Regulated versus Unregulated Flows at Russell
Unregulated Flow
Regulated Flow
Channel Capacity
Cumulative Roblin Precipitation from April 29
Cumulative Roblin Monthly Normal Precip.
Flow in CFS
Precipitation in mm
20,000
15,000
10,000
5,000
0
200
150
100
50
0
1/Apr/11
8/Apr/11
15/Apr/11
22/Apr/11
29/Apr/11
6/May/11
13/May/11
20/May/11
27/May/11
3/Jun/11
10/Jun/11
17/Jun/11
24/Jun/11
1/Jul/11
8/Jul/11
15/Jul/11
22/Jul/11
29/Jul/11
5/Aug/11
12/Aug/11
19/Aug/11
26/Aug/11
2/Sep/11

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Record Flooding: Manitoba

River	Return Period Years): Regulated Peak Flow (Provisional)
Qu'Appelle at Welby	110 record
Assiniboine at Russell	91record
Assiniboine at Brandon	250 record
Assiniboine at Portage	220 record
Souris at Westhope	220 record
Souris at Melita	180 record
Souris @ Wawanesa	130 record
Fairford River	380 record
Lake Manitoba	400 record
Red River at James Ave	30 (6th Highest)

1997 versus 2011 Flood

- Landowners on lakes significantly impacted
- 1997 flood much shorter and localized (Mainly Red River impacted0
- 2011 Geographically extensive
- ‘Improved tech’ flood management
- Satellite imagery: monitoring networks
- Ice breaking: real-time information
- Forecasting: communications
- Rapid deployment of emergency flood protection equipment

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5 Lessons Learned/Opportunities

- Existing rating curves may not apply for floods not recorded before
- At high water levels there was little storage of water in the US Marsh areas for the Souris River; unusual hydrological phenomenon (Area of Research)
- Timely, accurate and clear communication of information was critical
- Further research needed to better quantify surface runoff from snow melt as distinct from rain generated runoff, or combined
- Identifying critical resources prior to potential major flooding
- Need for more physically based and easy to run operational models and improved hydro-meteorological network
- Need for real data at ungauged (indexed) locations

Managing people and processes

- During a major flood event, there may be little time for analysis and discussion regarding whether to issue individual flood warnings
- Given that floods can occur any time of day or night, less experienced staff on duty need clear guidance on actions to take
- If procedures are not available, or do not cover all likely eventualities, vital actions may be overlooked
- Continuous auditing critical steps during the flooding event
- Need for detailed performance analysis during and post event
- Post event review, successes and failures, opportunities

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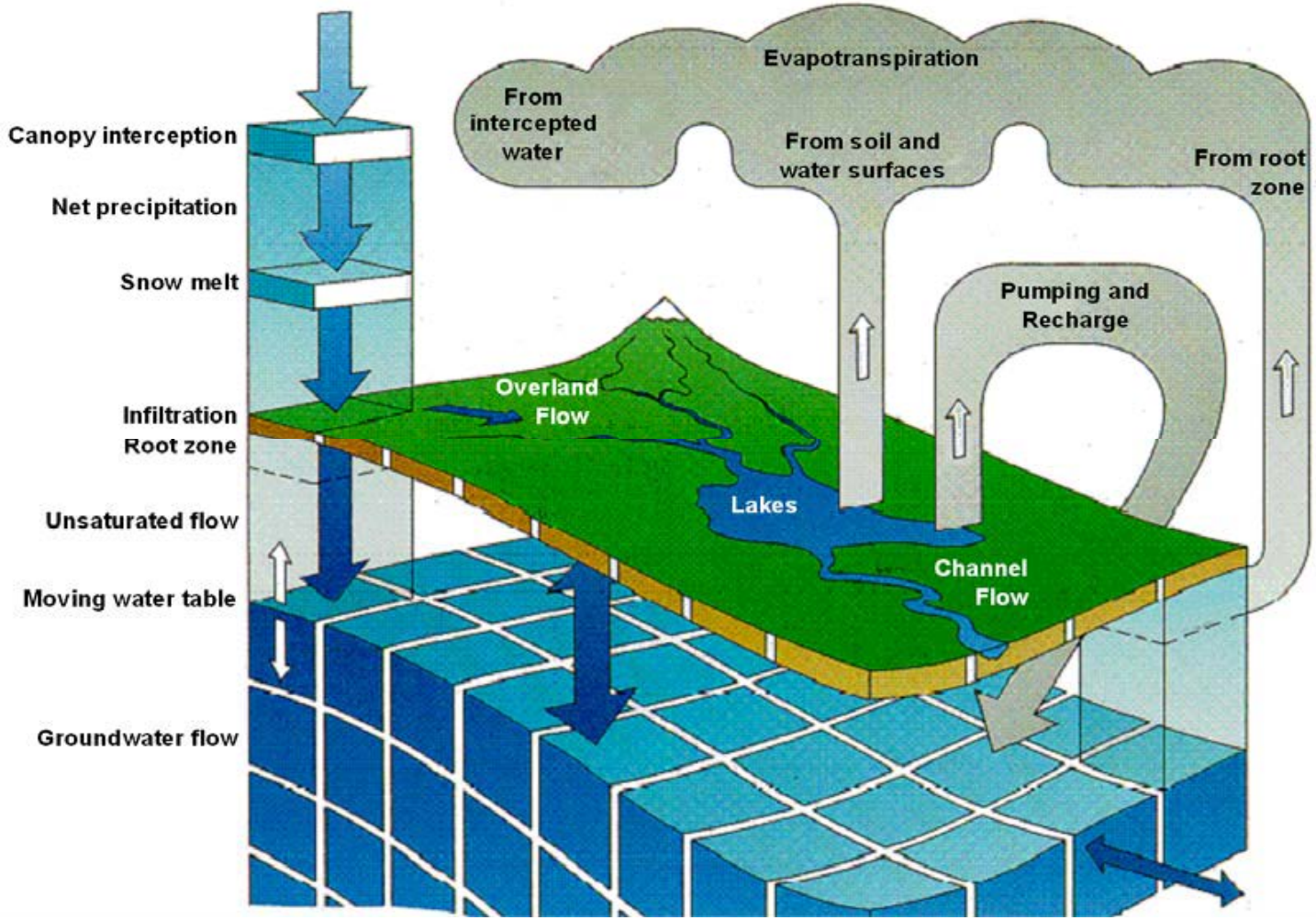
Flood Modelling Limitations/ Opportunities

Models accounting explicitly for :

- Depression storages/ contributing area
- Soil moisture distribution
- Storm movements & convective cells
- Land use and cover characterization
- Physics of snowmelt
- Frozen soils & infiltration
- Two dimensional overbank flows
- Runoff from rainstorms
- Ice related flooding
- Hysteresis effects like in 2011

Methodologies: New Initiatives

(Initial tests by Stantec (2011))



Continuous Simulation Models: Hydrological Processes in MIKE – SHE

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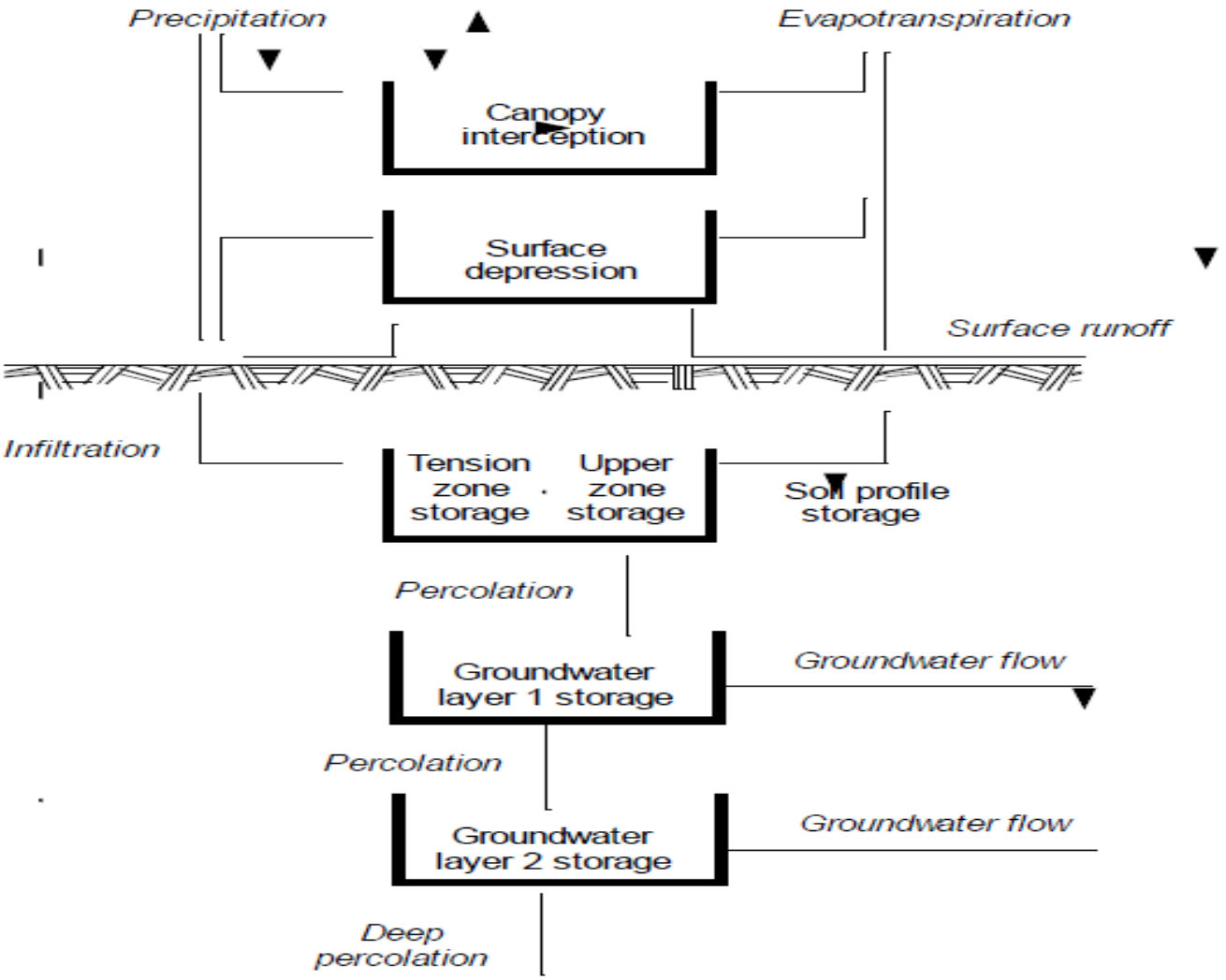
Methodologies: HEC-HMS (Snow-Melt & SMA- 5 Layer Model)



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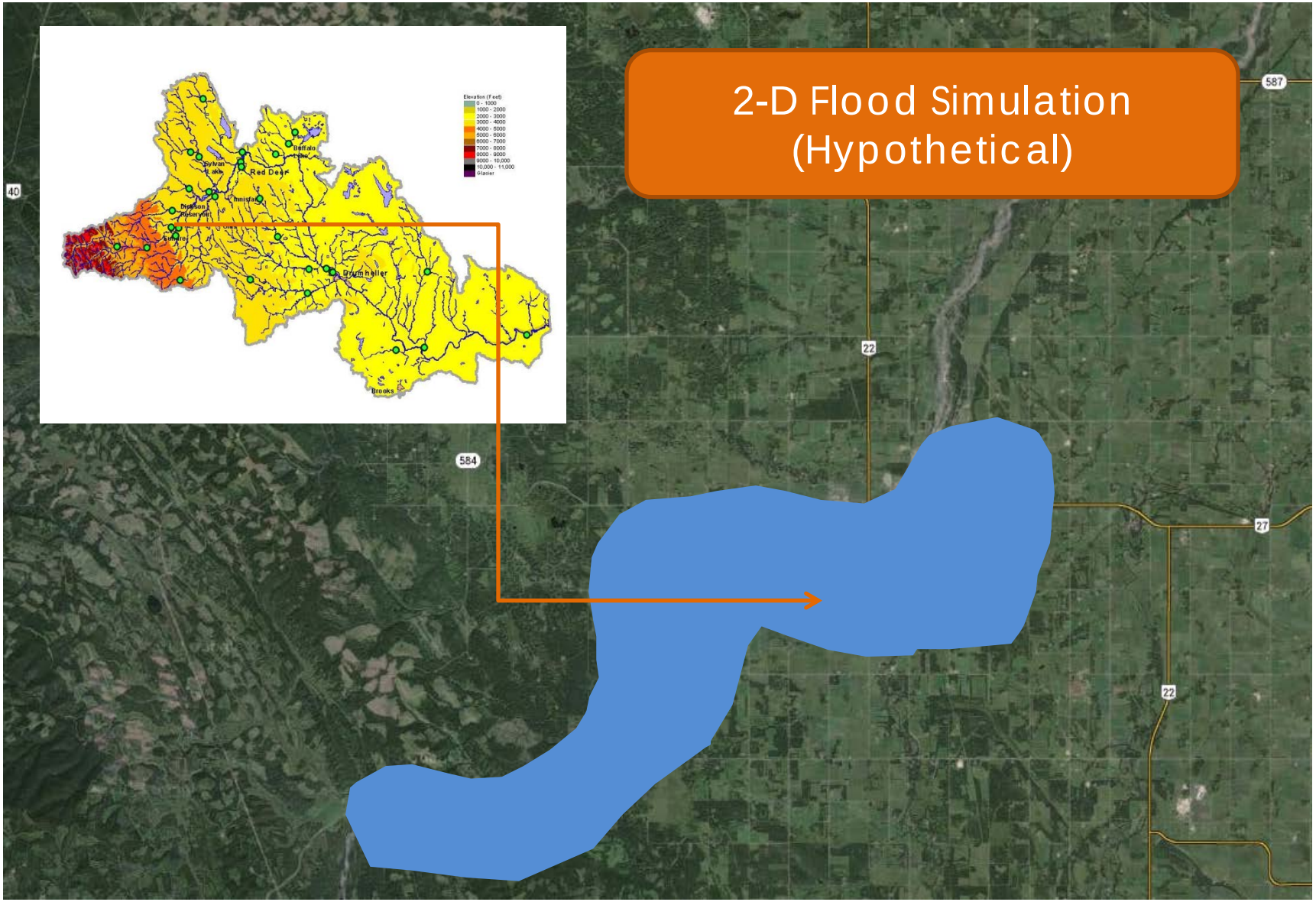
Emerging Technologies and Opportunities



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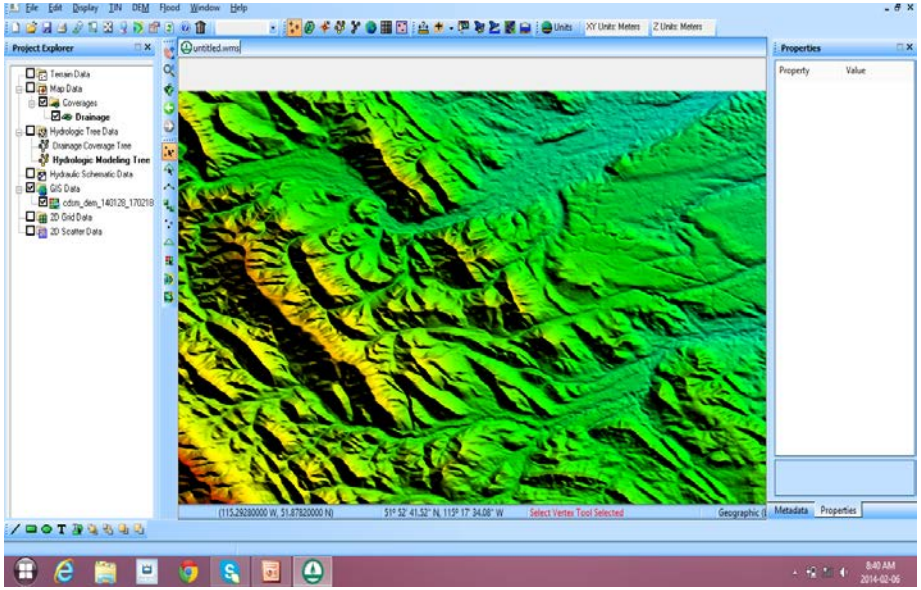
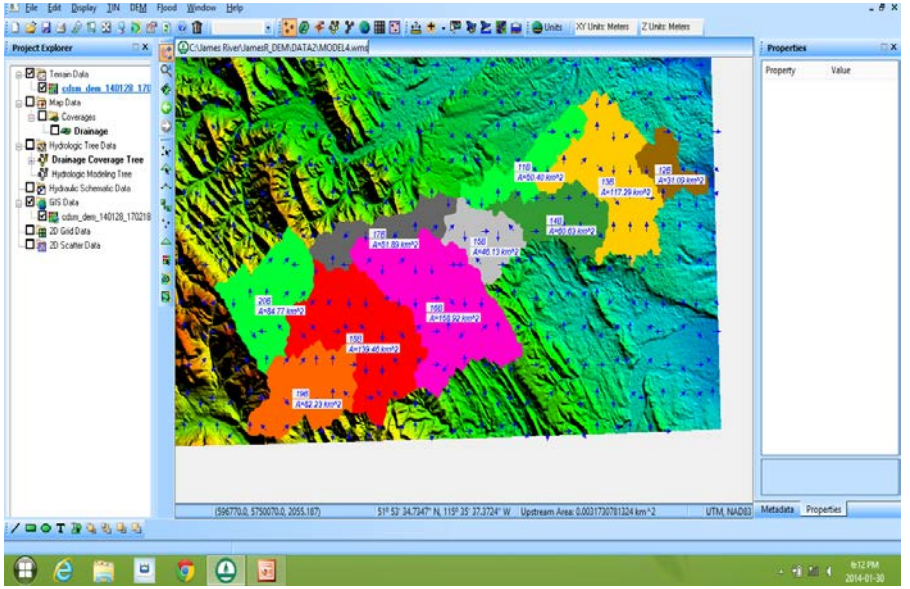
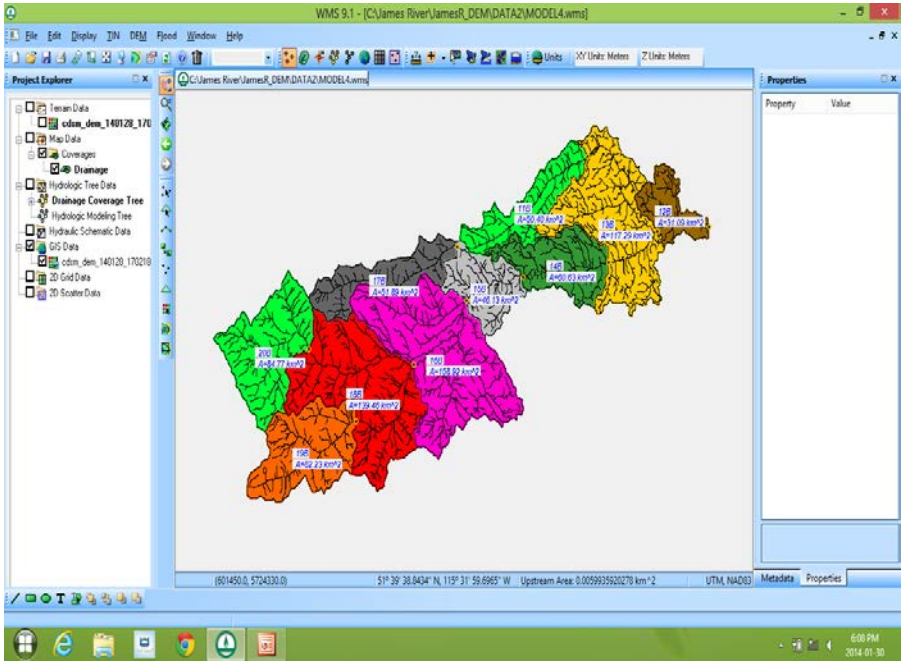
GIS Applications and Distributed Modelling







- Better definition of spatial variability through GIS Applications
- Integration of multi-layer system of data and math operations

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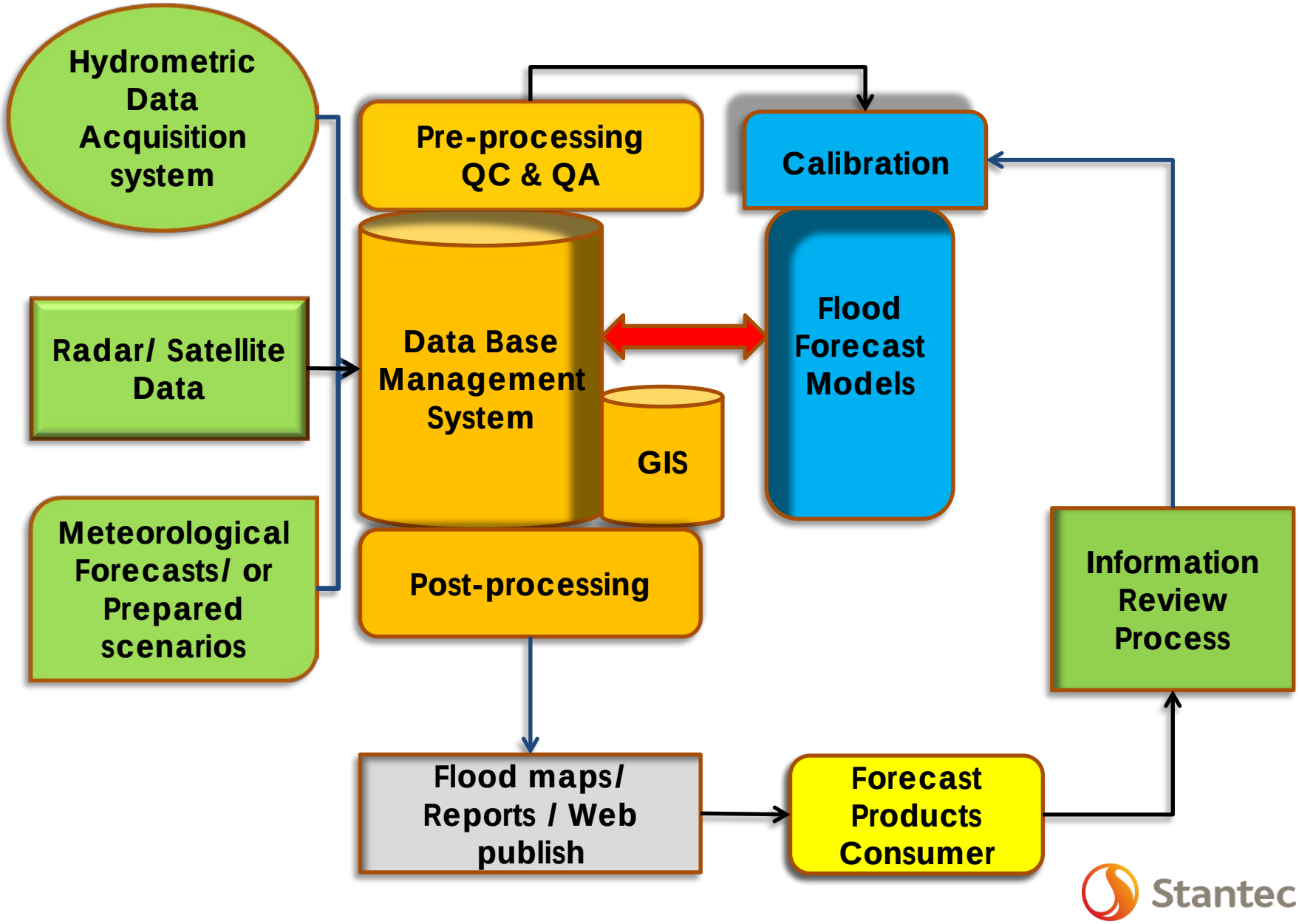
Need for Flood Warning Decision Support System



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Stantec's Database Management System

Stantec has acquired the AQUARIUS system, a powerful platform that can provide water agencies with a centralized and optimized solution that to enable fast and easy access to a variety of data sets that constitute a part of an integrated environmental monitoring program.

To date we have the capacity to:

1. Manage all our hydrometric data, including all of the historical WSC data sets
2. Manage our monitoring network through telemetry and near real time, automated data uploads and QA/QC
3. Provide a centralized set of tools for detailed hydrologic analyses within the AQUARIUS environment
4. Provide a customized set of tools for hydrometric and climate station management

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Stantec's Current Flood Related Projects

Client	Project Name	Tasks
ESRD	Flood Forecasting Performance Review (Ongoing)	• Review/Evaluation of Flood Forecasting Techniques Applied in Different Countries
ESRD	Flood Vulnerability Assessment (Ongoing)	• Hydrologic Analysis & Modelling • Hydrometric Data Assessment
Flood Task Force	Red Deer Feasibility Study (Just completed)	• Hydrologic Analysis Modelling; • Flood evaluation and Mitigation Alternatives

Stantec's Expertise & Experience

- Hydrologic/ Hydrodynamic (Flood) modelling
- Forecasting
- Climatology/ Meteorology
- Flood mitigation/ infrastructure
- Flood mapping
- Hydrometerologic database management

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6 Concluding Remarks

- Review and improvement of existing hydrometric network systems
- Acquisition of more LiDar/ bathymetry data to enable detailed mapping and modelling
- Consider precipitation densification through programmes like Community Collaborative Rain Hail and Snow Program (CoCoRaHS), WeatherFarm etc.
- Accounting for uncertainties and climate change
- Implementation of data assimilation techniques
- Implementation of adaptive parameter schemes
- Implementation of flood forecasting platform: e.g. use of AQUARIUS, FEWS, WI
- Testing & improvement of existing hydrologic/ hydraulic models
- Testing and comparison of various hydrologic models

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Thank you.

Questions?