2013Google, Imagery Mar 29, 2009

April 24, 2014

Middle and Lower Chase River Dams Dam Safety Analysis

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Dam Safety Analysis

Dam Safety Analysis Framework

- CDA Guidelines :
- *“Safety Management is ultimately concerned with management of risk and should provide answers to the following questions,*
  - *What can go wrong?*
  - *What is the likelihood (probability) of it happening?*
  - *If it occurs, what are the possible consequences?”*
- Two approaches considered
  - Risk-Informed Approach
  - Traditional Standards-Based Approach

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Dam Safety Analysis Framework

- Risk Informed Approach
  - CDA Guidelines : *"In view of the large uncertainties involved, a risk-informed approach is encouraged. Such an approach includes traditional deterministic standards-based analysis as one of many considerations, as shown in Figure 6-1".*
    - Such an approach has been adopted in the dam safety analysis for Colliery Dams – e.g. seismic analysis (numerical (FLAC) modelling), H and H analyses.
    - The deterministic analyses have been supported by extensive additional site information
  - Established, performance-based criteria
  - This approach, with the performance based criteria, forms the basis for determination of dam safety conformance.

Figure 6-1: Integrated (Risk-Informed) Decision-Making
[Source: Bulletin 154, ICOLD 2011]

Dam Safety Analysis

Dam Safety Analysis Framework

- Traditional Standards-based Approach
  - Means of comparative assessment – to determine how dam safety performs relative to traditional Approach – a means of “bench-marking”.
  - Demonstrate justification for variation from the Traditional Standards-based Criteria, if Risk-Informed performance targets are met.

Consequence Classification

Middle Dam Ref – Schedule 1, BC Dam Safety Regulation

- Considers Middle Dam consequences, separate from failure of Lower Dam (ie route release hydrograph through Lower Dam).
- Affected areas
  - 1) Area between MD and Lower Dam, and Lower Dam reservoir
  - 2) Area below Lower Dam

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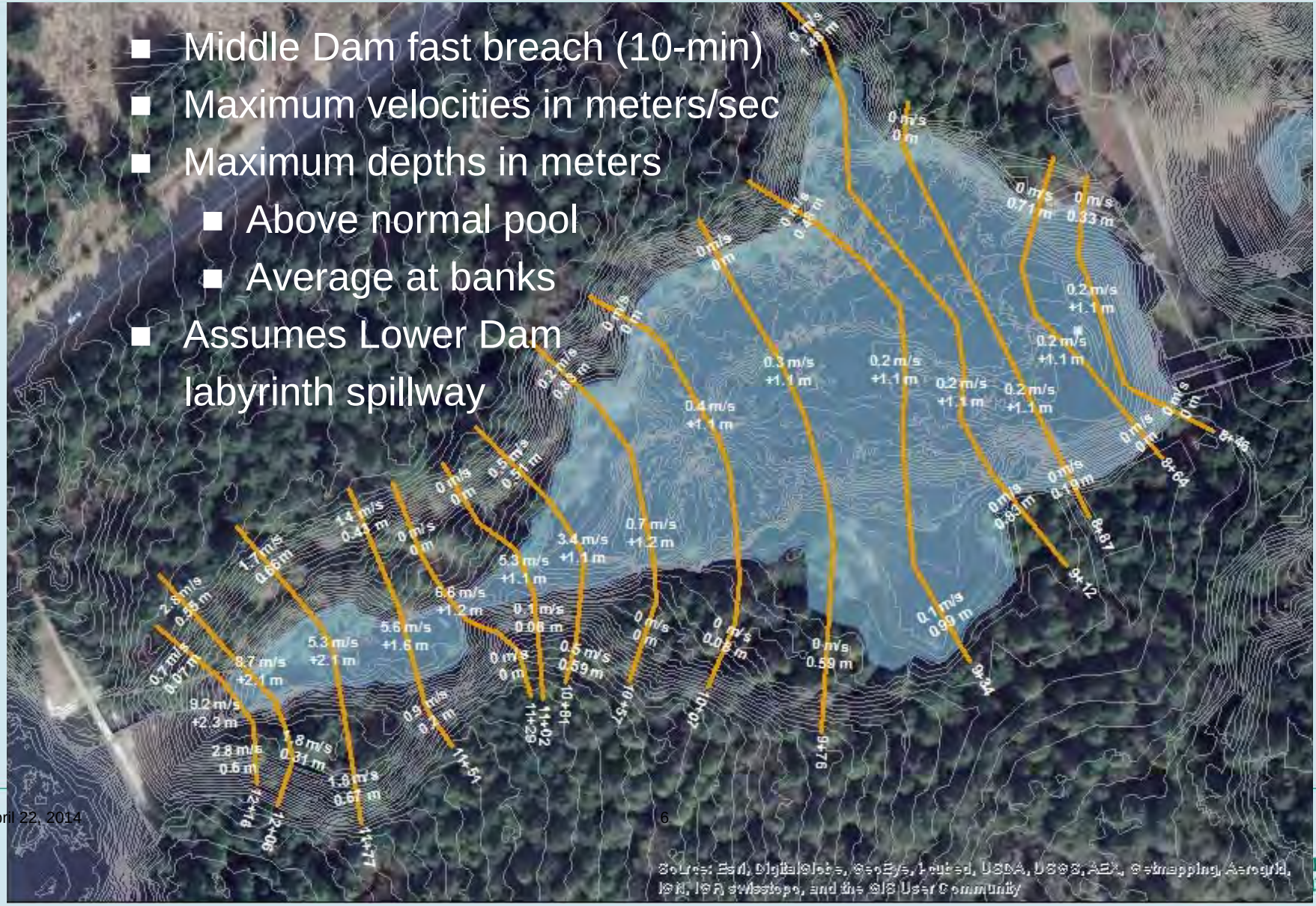
Middle Dam Breach Inundation Map

- Middle Dam fast breach (10-min)
- Maximum velocities in meters/sec
- Maximum depths in meters
  - Above normal pool
  - Average at banks
- Assumes Lower Dam labyrinth spillway



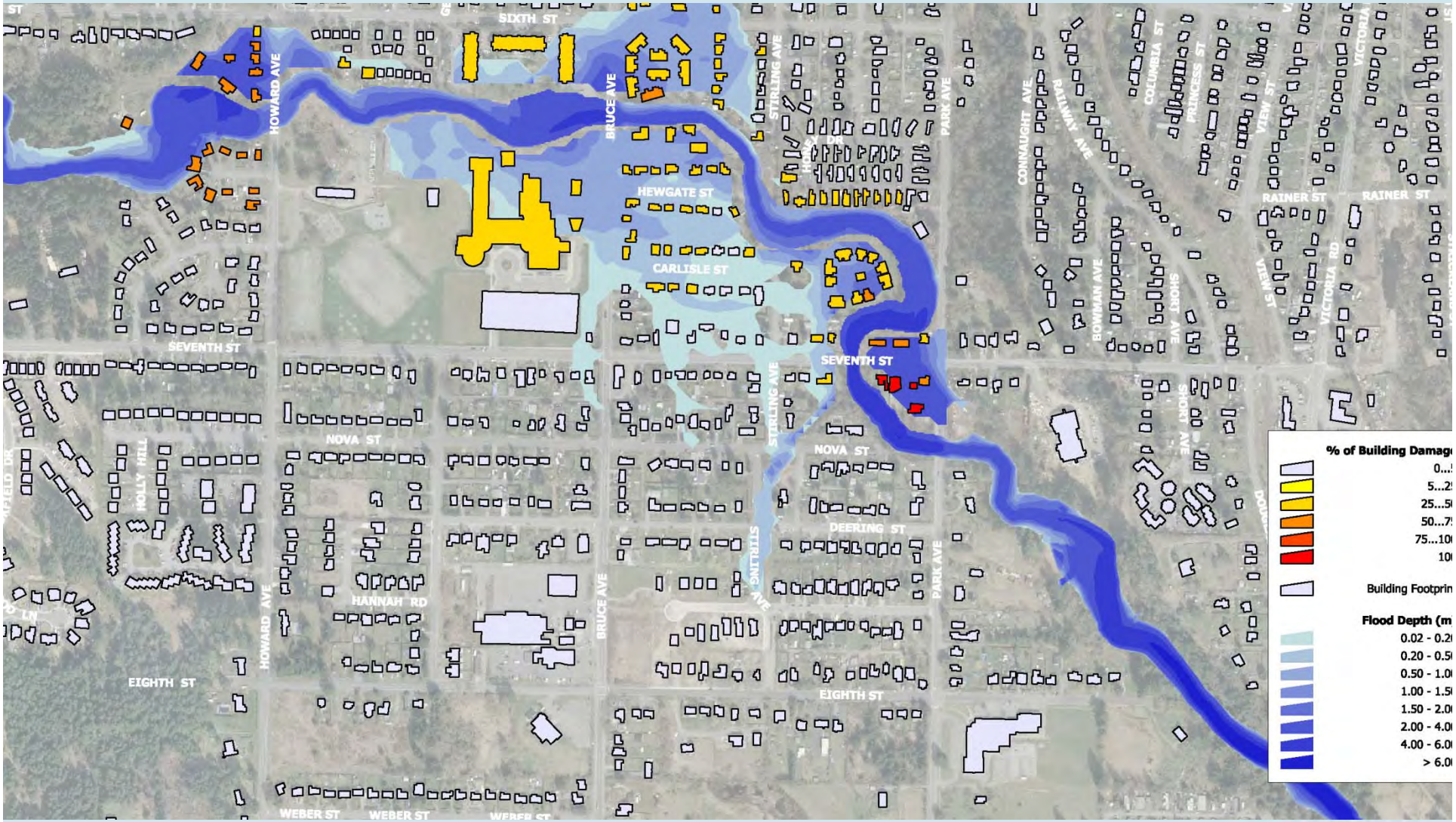
Consequence Classification

Middle Dam Ref – Schedule 1, BC Dam Safety Regulation

- Population at Risk.
  - Permanent (populated area downstream of Lower Dam)
- Environmental and Cultural
  - Significant loss of important wildlife habitat (not critical) downstream important (not critical) fish habitat for salmon in the lower Chase River.
  - Restoration or compensation is highly possible.
  - Unique landscapes or sites of cultural significance?
- Consequences – Loss of Life; Infrastructure and Economic
  - Two scenarios – hydrology (this governs over seismic)
    - Base case - SC19 – PMF plus MD breach (60 minutes)
    - Sensitivity case – SC3 – PMF plus MD breach (10 minutes)

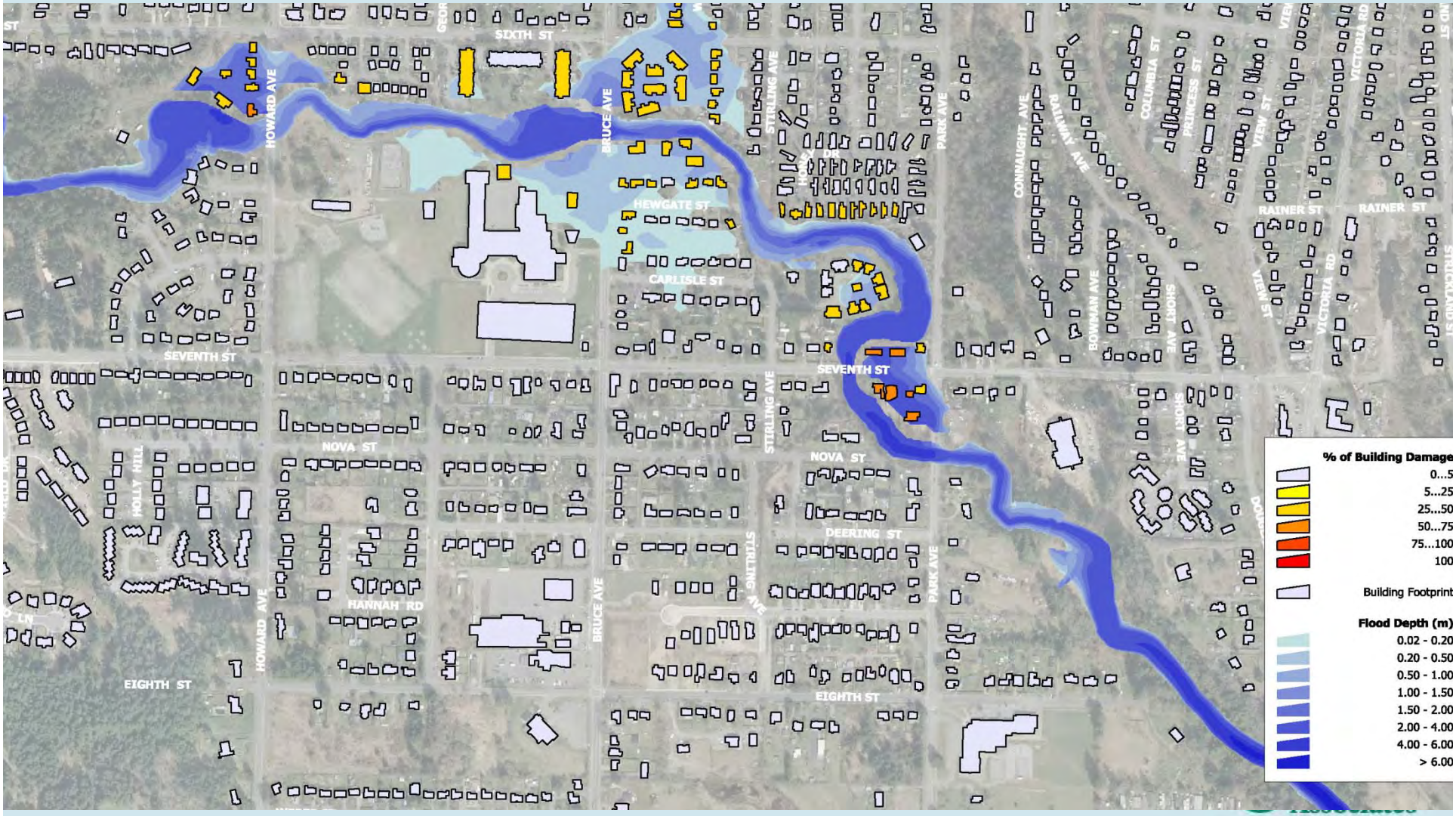
Consequence Classification

Middle Dam Sensitivity case – SC3 – PMF plus MD breach (10 minutes)



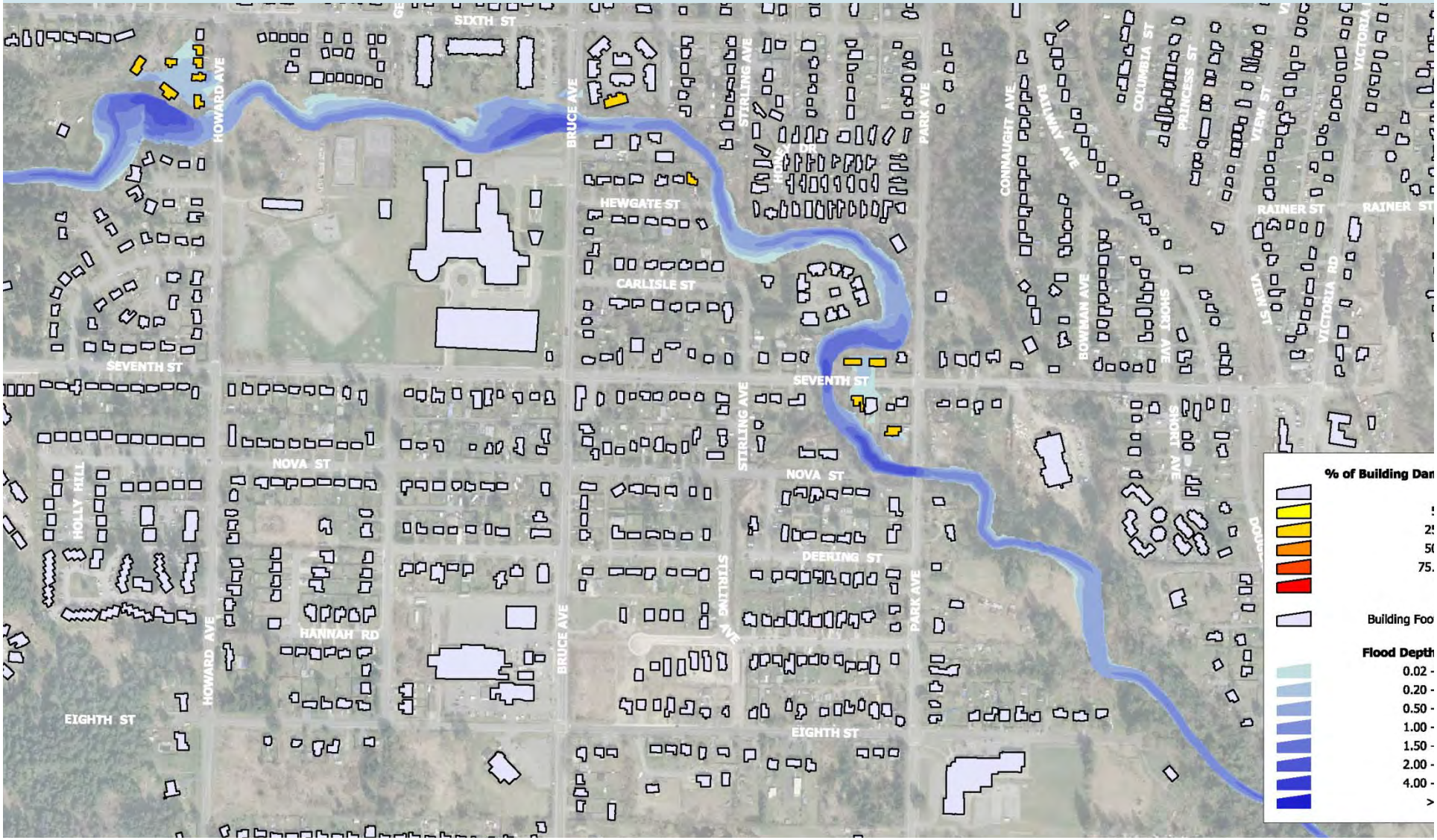
Consequence Classification

Middle Dam SC8 – PMF, no MD breach



Consequence Classification

Middle Dam SC1 – Seismic MD breach (10 min)



Consequence Classification

Middle Dam Ref – Schedule 1, BC Dam Safety Regulation

- Consequences – Loss of Life; Infrastructure and Economic
  - Two scenarios – hydrology (this governs over seismic)
    - Base case - SC19 – PMF plus MD breach (60 minutes)
    - Sensitivity case – SC3 – PMF plus MD breach (10 minutes)

Scen ID	Scenario Consequences					Incremental Consequences		
	Building Damage	Contents Damage	Total Damage	Number Fatalities	Max Ind Ann P[F]	Total Damage	Number Fatalities	Max Ind Ann P[F]
SC19	$6.2	$3.9	$10.1	4.4E-01	5.8E-02	$3.4	3.8E-01	5.0E-02
SC3	$7.6	$4.4	$12.1	2.0E+00	1.9E-01	$5.3	1.9E+00	1.8E-01

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Consequence Classification – Middle Dam

Dam failure consequences classification	Population at risk	Consequences of failure Loss of life	Environment and cultural values	Infrastructure and economics
Significant	Temporary only[2]	Low potential for multiple loss of life.	No significant loss or deterioration of (a) important fisheries habitat or important wildlife habitat, (b) rare or endangered species, or (c) unique landscapes or sites of cultural significance, and restoration or compensation in kind is highly possible.	Low economic losses affecting limited infrastructure and residentia buildings, public transportation or services or commercial facilities, o some destruction of or damage to locations used occasionally and irregularly for temporary purposes
High	Permanent[3]	10 or fewer	Significant loss or deterioration of (a) important fisheries habitat or important wildlife habitat, (b) rare or endangered species, or (c) unique landscapes or sites of cultural significance, and restoration or compensation in kind is highly possible.	High economic losses affecting infrastructure, public transportatior or services or commercial facilities or some destruction of or some severe damage to scattered residential buildings.
Very high	Permanent[3]	100 or fewer	Significant loss or deterioration of (a) critical fisheries habitat or critical wildlife habitat, (b) rare or endangered species, or (c) unique landscapes or sites of cultural significance, and restoration or compensation in kind is possible but impractical.	Very high economic losses affectin important infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas.

Consequence Classification

Lower Dam

- Assumes cascading failure of Middle Dam to Lower Dam
- Affected areas
  - Area downstream of Lower Dam
- Population at Risk.
  - Permanent (populated area below Lower Dam)
- Environmental and Cultural
  - Significant loss of important wildlife habitat (not critical) downstream important (not critical) fish habitat for salmon in the lower Chase River.
  - Restoration or compensation is highly possible.
  - Unique landscapes or sites of cultural significance?

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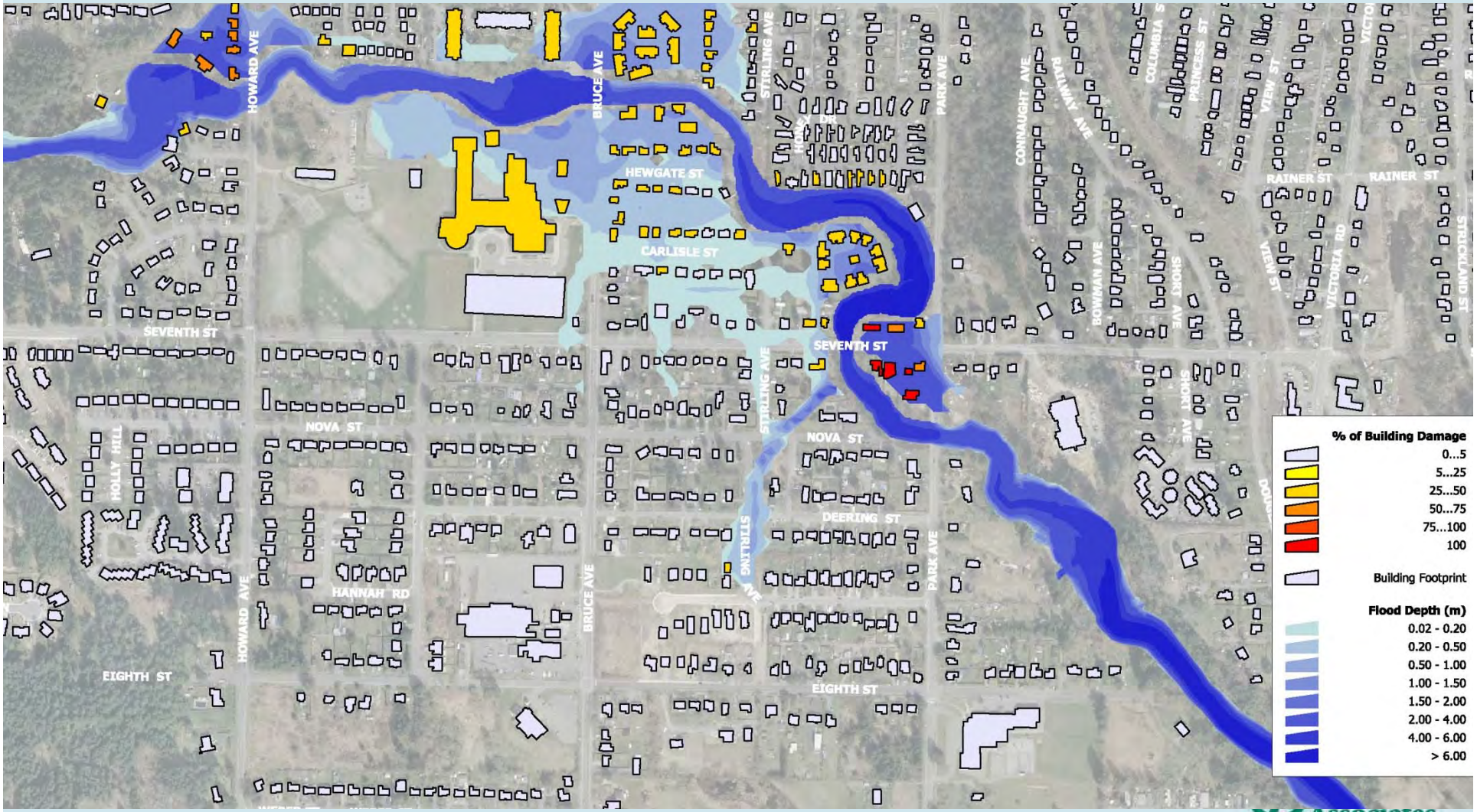
Consequence Classification

Lower Dam

- Consequences – Loss of Life; Infrastructure and Economic
  - Two scenarios
    - Base case - SC13 – PMF plus MD breach (60 minutes), LD breach (120 min)
    - Sensitivity case – SC14 – PMF plus MD breach (10 minutes), LD breach (10 min)

Consequence Classification

Lower Dam Base case - SC13 – PMF plus MD breach (60 min.), LD breach (120 min)



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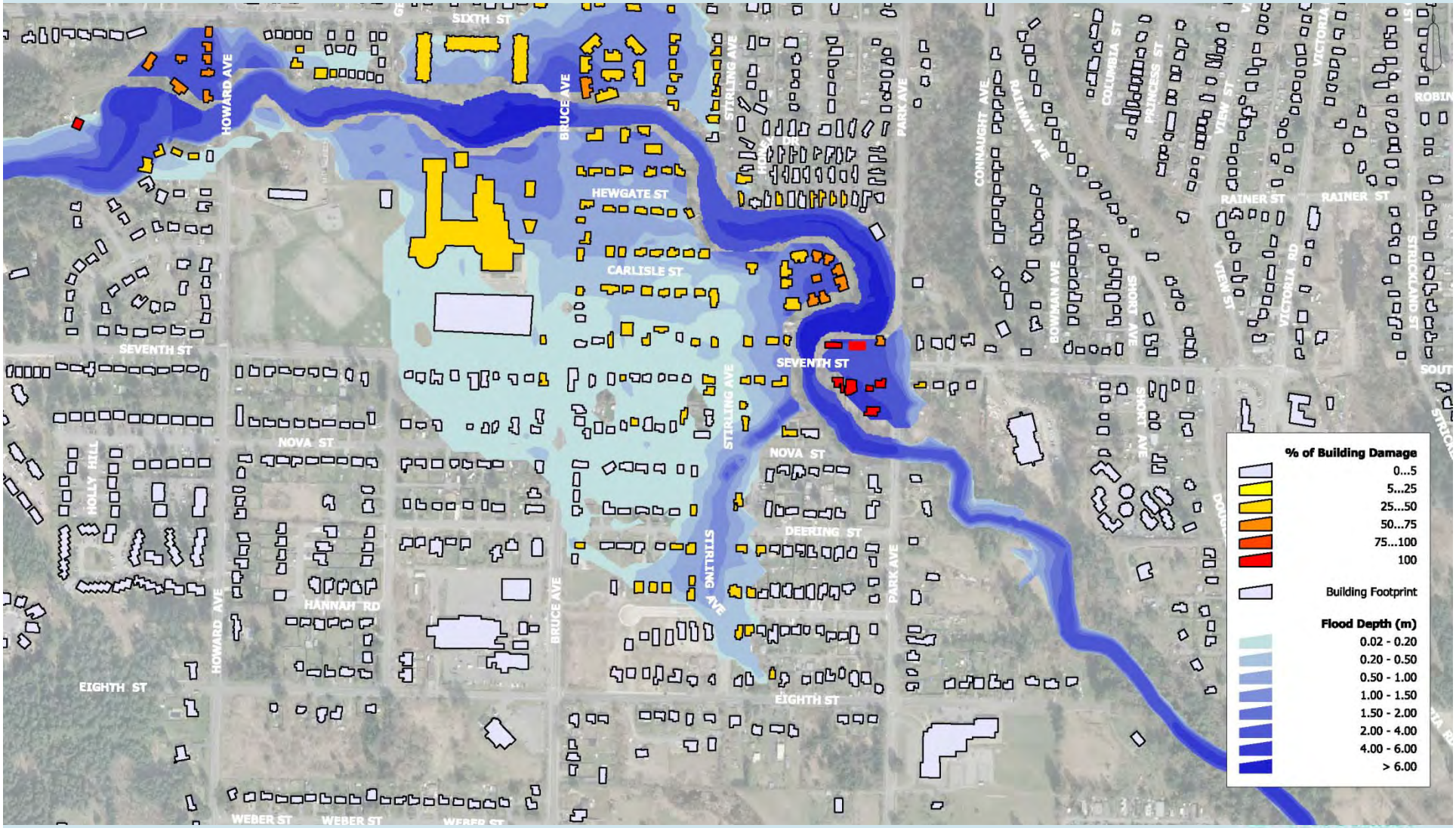
Consequence Classification

Lower Dam Sensitivity case – SC14 – PMF plus MD breach (10 min), LD breach (10 min)



Consequence Classification

Lower Dam Ref – Schedule 1, BC Dam Safety Regulation

- Consequences – Loss of Life; Infrastructure and Economic
  - Two scenarios
    - Base case - SC13 – PMF plus MD breach (60 minutes), LD breach (120 min)
    - Sensitivity case – SC14 – PMF plus MD breach (10 minutes), LD breach (10 min)

	Scenario Consequences					Incremental Consequences		
cen D	Building Damage	Contents Damage	Total Damage	Number Fatalities	Max Ind Ann P[F]	Total Damage	Number Fatalities	Max Ind Ann P[F]
C13	$5.8	$3.4	$9.2	1.06E+00	1.12E-01	$2.5	1.0E+00	1.0E-01
C14	$9.5	$5.5	$15.0	1.12E+01	6.40E-01	$8.2	1.1E+01	6.3E-01

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Consequence Classification – Lower Dam

Dam failure consequences classification	Population at risk	Consequences of failure Loss of life	Environment and cultural values	Infrastructure and economics
Significant	Temporary only[2]	Low potential for multiple loss of life.	No significant loss or deterioration of (a) important fisheries habitat or important wildlife habitat, (b) rare or endangered species, or (c) unique landscapes or sites of cultural significance, and restoration or compensation in kind is highly possible.	Low economic losses affecting limited infrastructure and residentia buildings, public transportation or services or commercial facilities, o some destruction of or damage to locations used occasionally and irregularly for temporary purposes
High	Permanent[3]	10 or fewer	Significant loss or deterioration of (a) important fisheries habitat or important wildlife habitat, (b) rare or endangered species, or (c) unique landscapes or sites of cultural significance, and restoration or compensation in kind is highly possible.	High economic losses affecting infrastructure, public transportatior or services or commercial facilities or some destruction of or some severe damage to scattered residential buildings.
Very high	Permanent[3]	100 or fewer	Significant loss or deterioration of (a) critical fisheries habitat or critical wildlife habitat, (b) rare or endangered species, or (c) unique landscapes or sites of cultural significance, and restoration or compensation in kind is possible but impractical.	Very high economic losses affectin important infrastructure, public transportation or services or commercial facilities, or some destruction of or some severe damage to residential areas.

Dam Remediation Approach

- Apply risk assessment to each remediation option under consideration.
- Demonstrate justification for variation from the Traditional Standards-based Criteria, if Risk-Informed performance targets are met.

Dam Remediation Approach

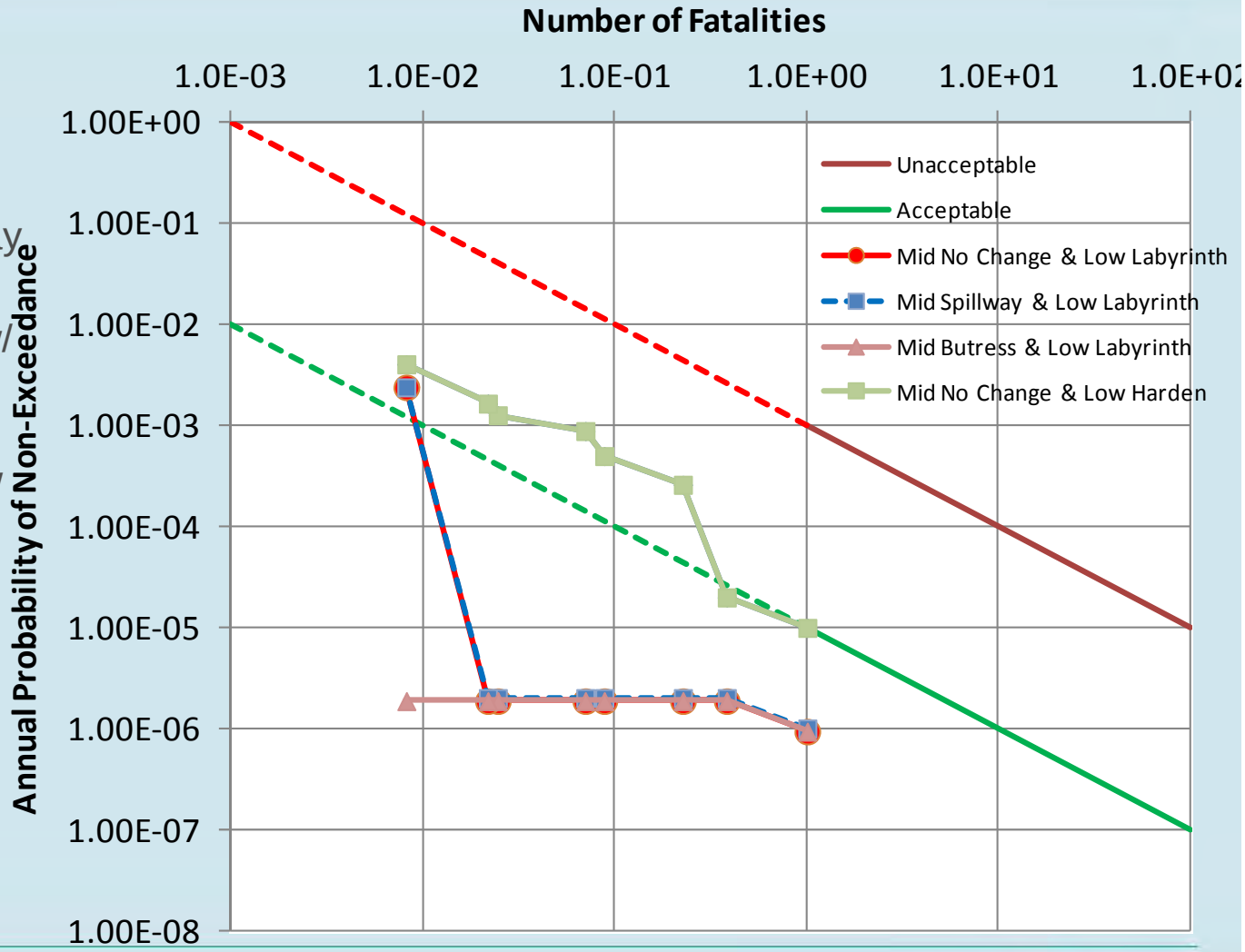
Middle Dam.

- Traditional Standards-Based Requirements - HIGH
  - Flood (design for capacity 1000 year + 1/3(PMF-1000year)) ~ 125m3/sec requirement,
    - current cap 62 m3/sec
  - Earthquake (design for 2475 period event)
    - Current - est 70% failure likelihood in 975 EQ, 30% likelihood in 475 EQ
- Options Under Consideration
  - As-is, (w/ LD spillway improvement)
  - Spillway upgrade (w/ LD spillway improvement)
  - Seismic buttress (w/ LD spillway improvement)

Dam Remediation Approach

Middle Dam.

- Options Under Consideration
  - As-is, (w/ LD spillway improvement)
  - Spillway upgrade (w/ LD spillway improvement)
  - Seismic buttress (w/ LD spillway improvement)



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Dam Remediation Approach

Middle Dam.

- Incremental Consequences (Risk Assessment)
  - As-is

For Labyrinth Lower Dam and no Middle Dam Change							Conditional Incr Conseq			
Storm	**Breach**		P[Middle Dam	P[Low|Mid]	P[Sceanrio]	Rep Sceanrio(s)		Damage	Fatalities	Ind Risk
PMF	Middle Dam only	1.90E-05	1.90E-05	0.95	1.81E-05	SC19		$ 3.4	3.8E-01	5.0E-02
	Middle Dam & Lower Dam			0.05	9.50E-07	SC13		$ 2.5	1.0E+00	1.0E-01
1000 yr	Middle Dam only	7.50E-04	7.31E-04	1.00	7.31E-04	SC11		$ 0.9	8.8E-02	8.3E-03
	Middle Dam & Lower Dam			0	0.00E+00	SC12		$ 2.7	2.3E-01	3.3E-02
100 yr	Middle Dam only	3.50E-03	2.75E-03	1.00	2.75E-03	SC18 (35% of SC17)	35%	$ 1.7	2.5E-02	3.6E-03
	Middle Dam & Lower Dam			0	0.00E+00	SC17		$ 4.9	7.0E-02	1.0E-02
Seismic	Middle Dam only		4.50E-03	0.53	2.40E-03	SC16 (10% of SC1)+LowR	10%	$ -	8.2E-03	4.0E-05
	Middle Dam & Lower Dam			0.47	2.10E-03	SC15 (30% of SC17)+Low	30%	$ 1.5	2.2E-02	3.1E-03
								$ 0.01	2.1E-04	2.4E-05

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Dam Remediation Approach

Middle Dam.

- Incremental Consequences (Risk Assessment)
  - Spillway upgrade

For Labyrinth Lower Dam and Middle Dam spillway

						Conditional Incr Conseq			
Storm	**Breach**	P[Middle Dam	P[Low|Mid]	P[Sceanrio]	Rep Sceanrio(s)		Damage	Fatalities	Ind Risk
PMF	Middle Dam only	6.00E-06	0.83	4.98E-06	SC19		$ 3.4	3.8E-01	5.0E-02
	Middle Dam & Lower Dam		0.17	1.02E-06	SC13		$ 2.5	1.0E+00	1.0E-01
1000 yr	Middle Dam only	0.00E+00	1.00	0.00E+00	SC11		$ 0.9	8.8E-02	8.3E-03
	Middle Dam & Lower Dam		0	0.00E+00	SC12		$ 2.7	2.3E-01	3.3E-02
100 yr	Middle Dam only	0.00E+00	1.00	0.00E+00	SC18 (35% of SC17)	35%	$ 1.7	2.5E-02	3.6E-03
	Middle Dam & Lower Dam		0	0.00E+00	SC17		$ 4.9	7.0E-02	1.0E-02
Seismic	Middle Dam only	4.50E-03	0.53	2.40E-03	SC16 (10% of SC1)+LowR	10%	$ -	8.2E-03	4.0E-05
	Middle Dam & Lower Dam		0.47	2.10E-03	SC15 (30% of SC17)+Low	30%	$ 1.5	2.2E-02	3.1E-03
							$ 0.00	6.9E-05	6.9E-06

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Dam Remediation Approach

Middle Dam.

- Incremental Consequences (Risk Assessment)
  - Seismic buttress

For Labyrinth Lower Dam and Middle Dam buttress

							Conditional Incr Conseq			
Storm	**Breach**		P[Middle Dam	P[Low|Mid]	P[Sceanrio]	Rep Sceanrio(s)		Damage	Fatalities	Ind Risk
PMF	Middle Dam only	1.90E-05	1.90E-05	0.95	1.81E-05	SC19		$ 3.4	3.8E-01	5.0E-02
	Middle Dam & Lower Dam			0.05	9.50E-07	SC13		$ 2.5	1.0E+00	1.0E-01
1000 yr	Middle Dam only	7.50E-04	7.31E-04	1.00	7.31E-04	SC11		$ 0.9	8.8E-02	8.3E-03
	Middle Dam & Lower Dam			0	0.00E+00	SC12		$ 2.7	2.3E-01	3.3E-02
100 yr	Middle Dam only	3.50E-03	2.75E-03	1.00	2.75E-03	SC18 (35% of SC17)	35%	$ 1.7	2.5E-02	3.6E-03
	Middle Dam & Lower Dam			0	0.00E+00	SC17		$ 4.9	7.0E-02	1.0E-02
Seismic	Middle Dam only		2.80E-03	0.00	0.00E+00	SC16 (10% of SC1)+LowR	10%	$ -	8.2E-03	4.0E-05
	Middle Dam & Lower Dam			1.00	2.80E-03	SC15 (30% of SC17)+Low	30%	$ 1.5	2.2E-02	3.1E-03
								$ 0.01	2.0E-04	2.6E-05

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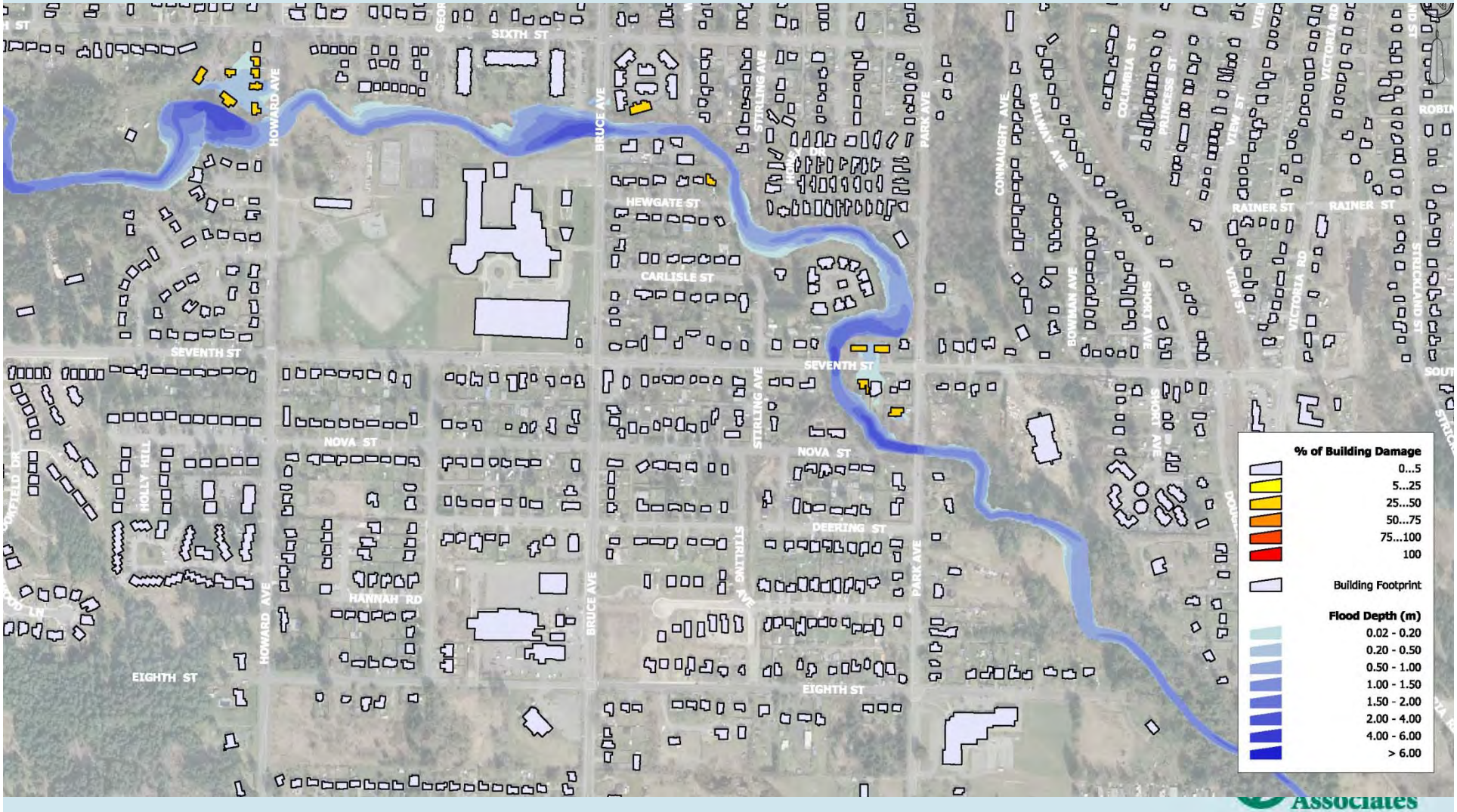
Dam Remediation Approach

Middle Dam. – Seismic (fast breach)



Dam Remediation Approach

Middle Dam.

- Proposed remediation
  - Select option, based on
    - Preliminary results indicate that ALARP Principle applies (ie above Acceptable condition)
    - Which option (Spillway, Buttress or nothing), gives greatest risk reduction.
      - Life safety
      - Economic
      - Environmental and cultural
    - Other considerations
      - Cost
      - Environmental – during construction and permanent
      - Aesthetic, Park use, etc

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Dam Remediation Approach

- Lower Dam.
- Traditional Standards-Based Requirements
  - Flood - design for capacity
    - 1000 year + 1/3(PMF-1000year)) ~ 125m3/sec requirement, (HIGH);
    - 1000 year + 2/3(PMF-1000year) ~ 143m3/sec requirement, Very High
    - current cap 35 m3/sec
  - Earthquake
    - design for 2475 period event) – HIGH;
    - ½ between 2475 and MCE (Very High)
    - Current seismic resistance – under analysis

Dam Remediation Approach

- Lower Dam.
- Options Under Consideration
  - Spillway upgrade (135 and 175 m3/sec capacity)
  - LD hardening

Dam Remediation Approach

- Lower Dam.
- Proposed remediation
  - Flood capacity requirement, select option based on (TC requirements)
    - Cost
    - Environmental – during construction and permanent
    - Aesthetic, Park use, etc
    - Additional capacity needed for future requirements, additional risk reduction?
  - Seismic
    - Complete analyses (FLAC and structural)
    - Determine incremental consequences for dam in as-is condition (risk assessment).
    - Assume dam is damaged by EDGM, and would require removal/reconstruction after event
  - Other – make use of other mitigation measures
    - E.g. instrumentation and rapid drawdown capabilities
    - Early warning system

Next Steps

- Complete seismic assessment of Lower Dam
  - Determine consequences
- Complete risk assessment
- Confirm dam remediation requirements
- Lower Dam – preliminary design and costing of options – May 8
- Middle Dam – conceptual design and costing of options – May 8 (target)