

GNSS – Structural Integrity Monitoring

CGSIC-USSLS

Seattle WA – August 14th, 2011

Gavin Schrock, PLS – Washington State Reference Network



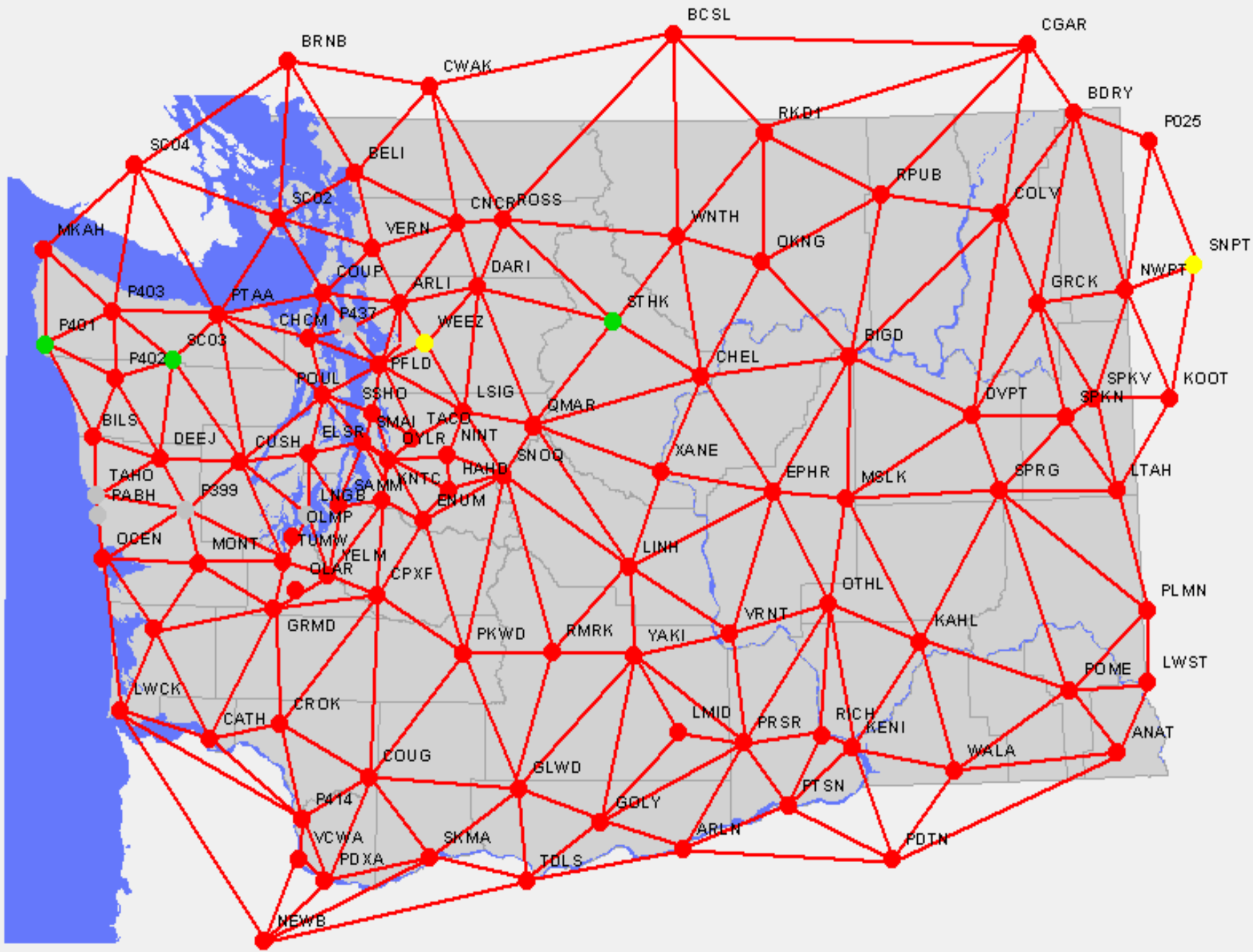
Managing RTN Geodesy, & Structural Integrity Monitoring

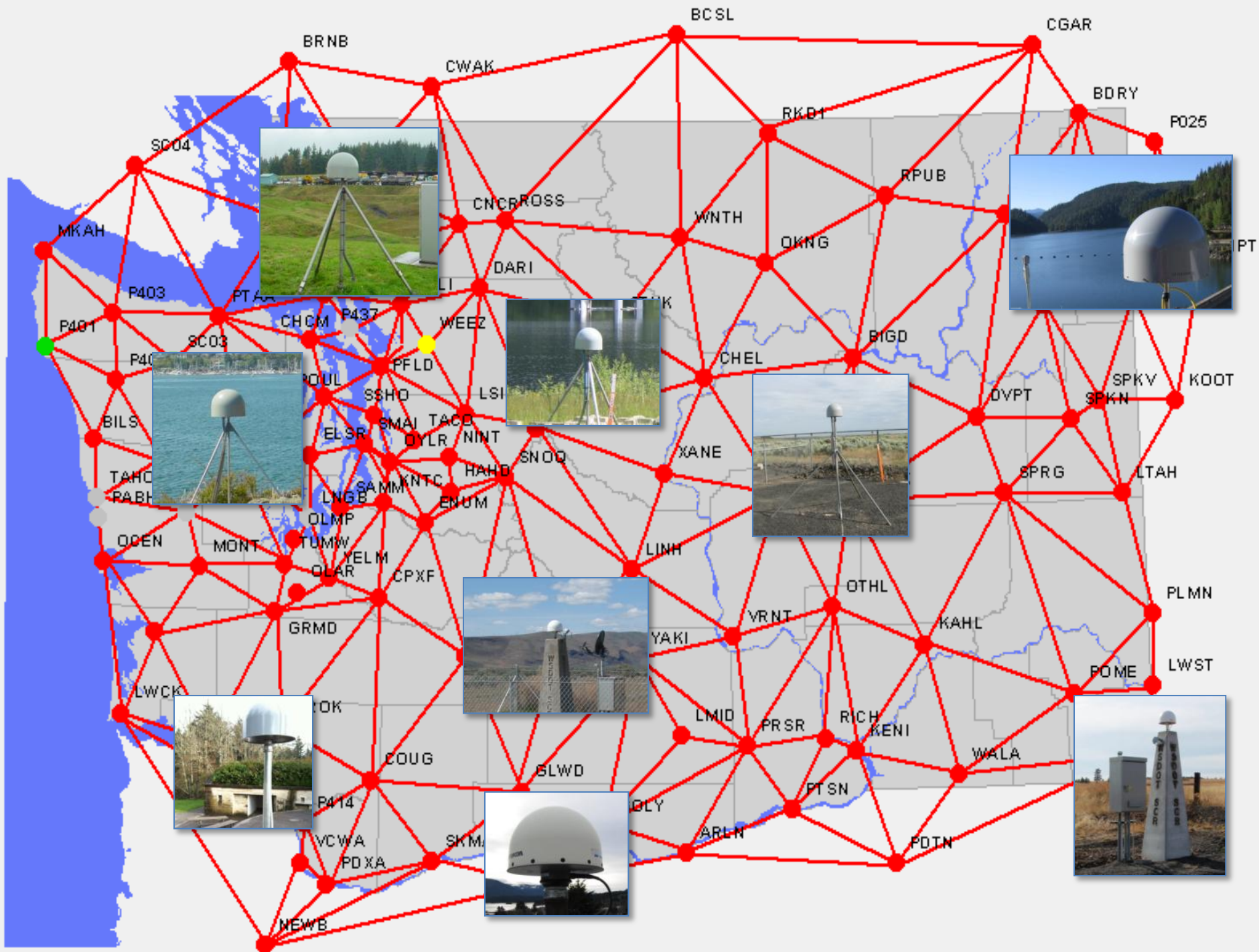
Network Integrity – Relative Integrity

Network Integrity - Registration to NSRS (NGS)

Regional Tectonics – Partnering with Academia

Monitoring - Dams, Bridges, Structures, Slides and ...





National CORS - HAHD



National Geodetic Survey - CORS



The NGS Data Sheet

See file [dsdata.txt](#) for more information about the datasheet.

```

DATABASE = NGSIDB , PROGRAM = datasheet95, VERSION = 7.88.2
1 National Geodetic Survey, Retrieval Date = MAY 17, 2012
DN5822 *****
DN5822 CORS - This is a GPS Continuously Operating Reference Station.
DN5822 DESIGNATION - HOWARD HANSON CORS ARP
DN5822 CORS_ID - HAHD
DN5822 PID - DN5822
DN5822 STATE/COUNTY- WA/KING
DN5822 COUNTRY - US
DN5822 USGS QUAD - EAGLE GORGE (1993)
DN5822
    
```

*CURRENT SURVEY CONTROL

NAD 83 (CORS) POSITION-	47 17 26.86644 (N)	121 47 17.04098 (W)	ADJUSTED
NAD 83 (CORS) ELLIP HT-	854.321 (meters)	(02/??/12)	ADJUSTED
NAD 83 (CORS) EPOCH	- 2002.00		
NAVD 88 ORTHO HEIGHT	- ** (meters)	** (feet)	
NAD 83 (CORS) X	-2,283,358.148 (meters)		COMP
NAD 83 (CORS) Y	-3,684,392.862 (meters)		COMP
NAD 83 (CORS) Z	- 4,664,380.700 (meters)		COMP
GEOID HEIGHT	-21.20 (meters)		GEOID09

WSRN-CWU Monitoring Initiative



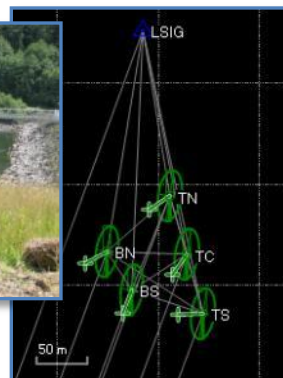
Ross Slide



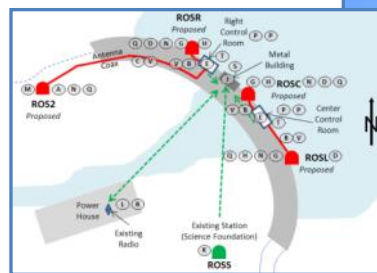
Viaduct



Tolt Dam



Municipal Tower

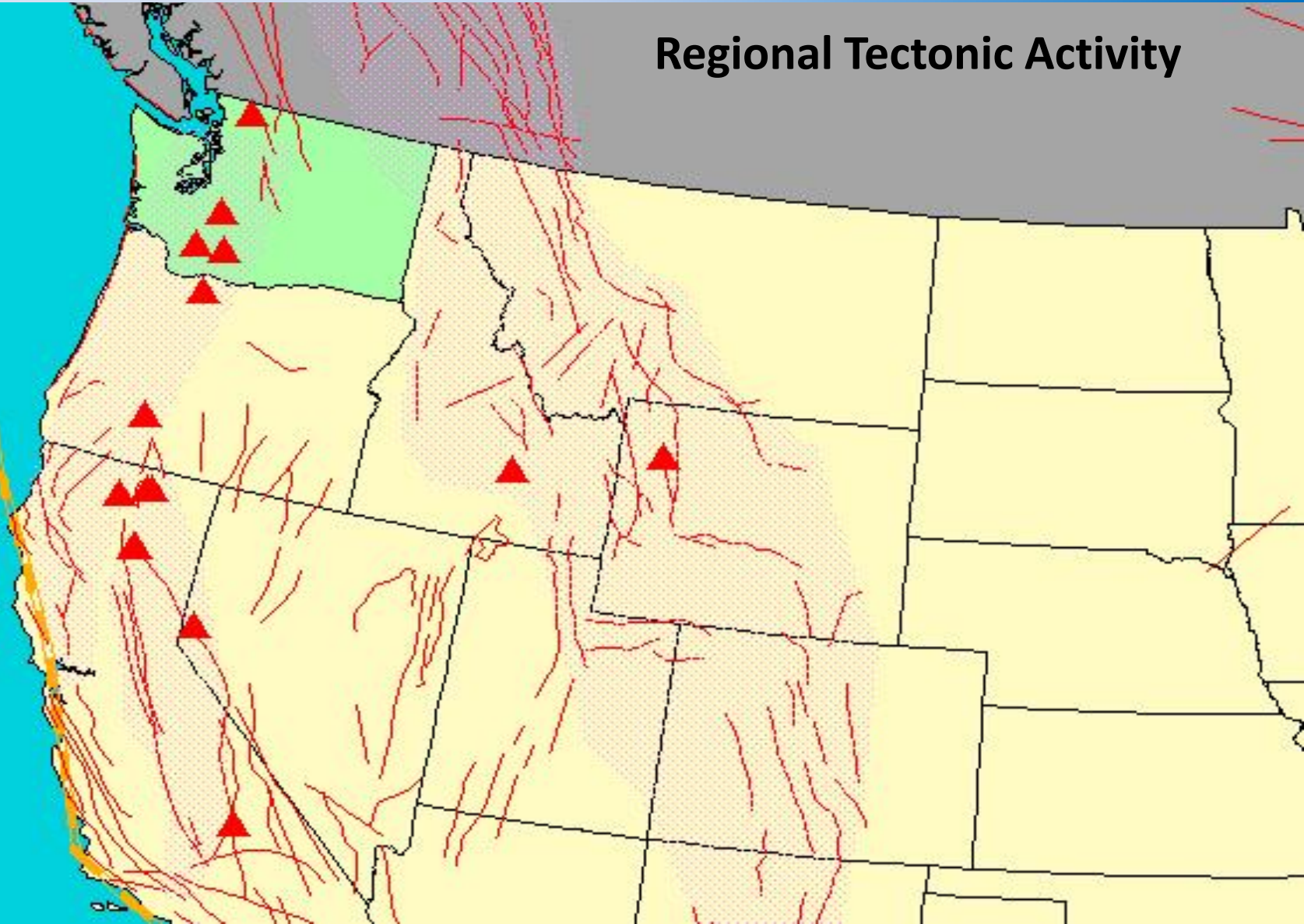


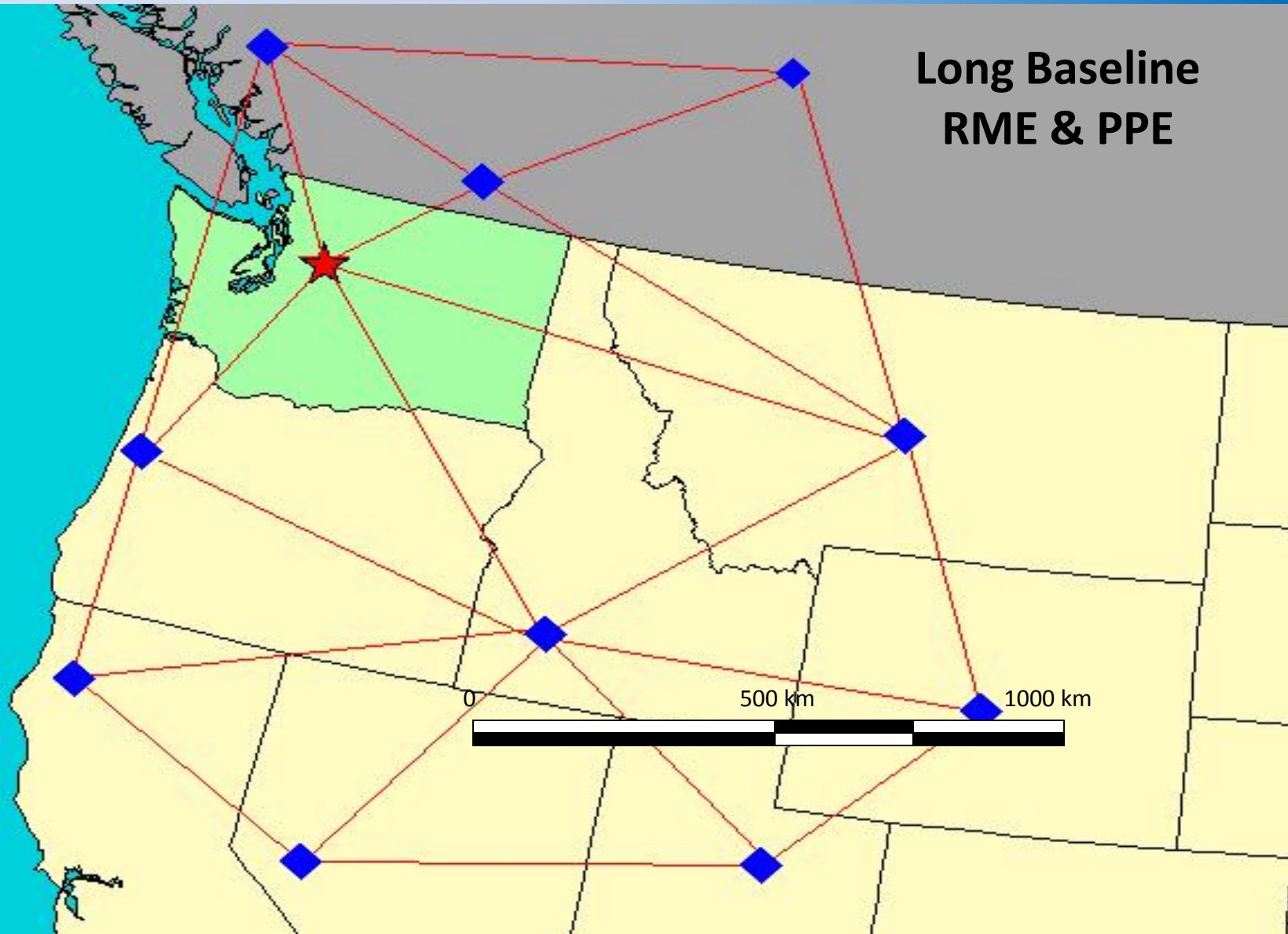
Ross Dam
(in progress)



520

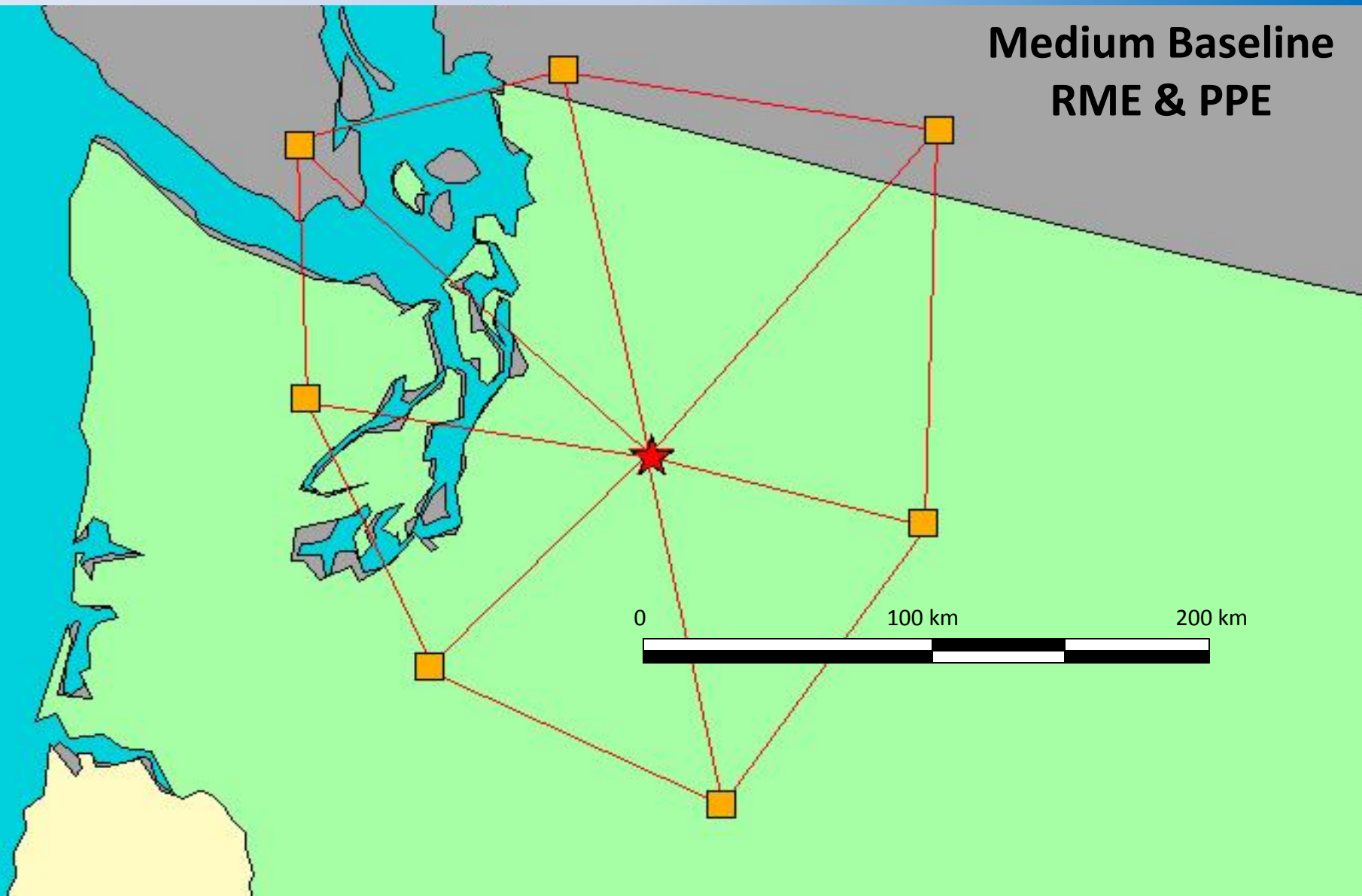
Regional Tectonic Activity

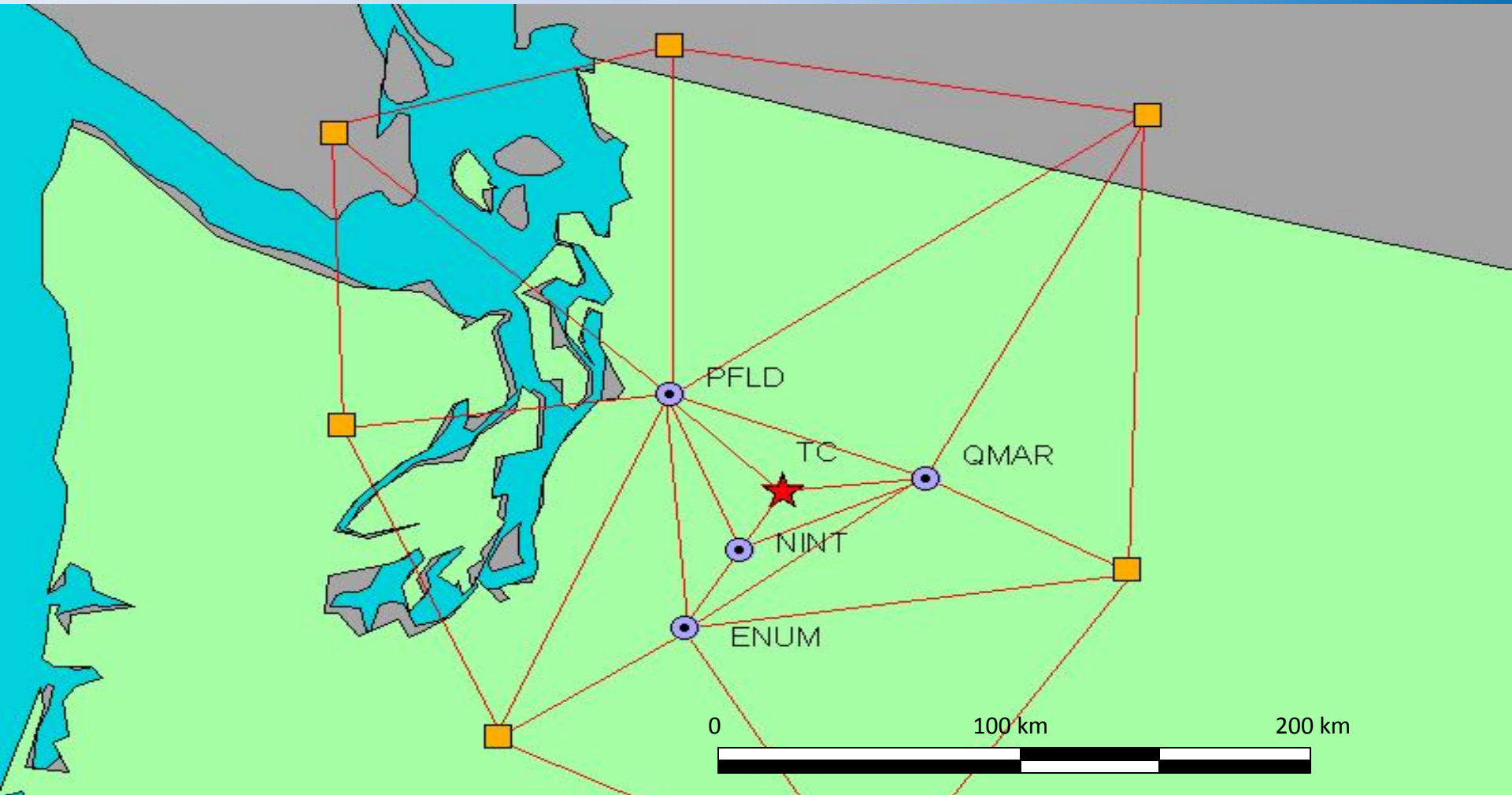




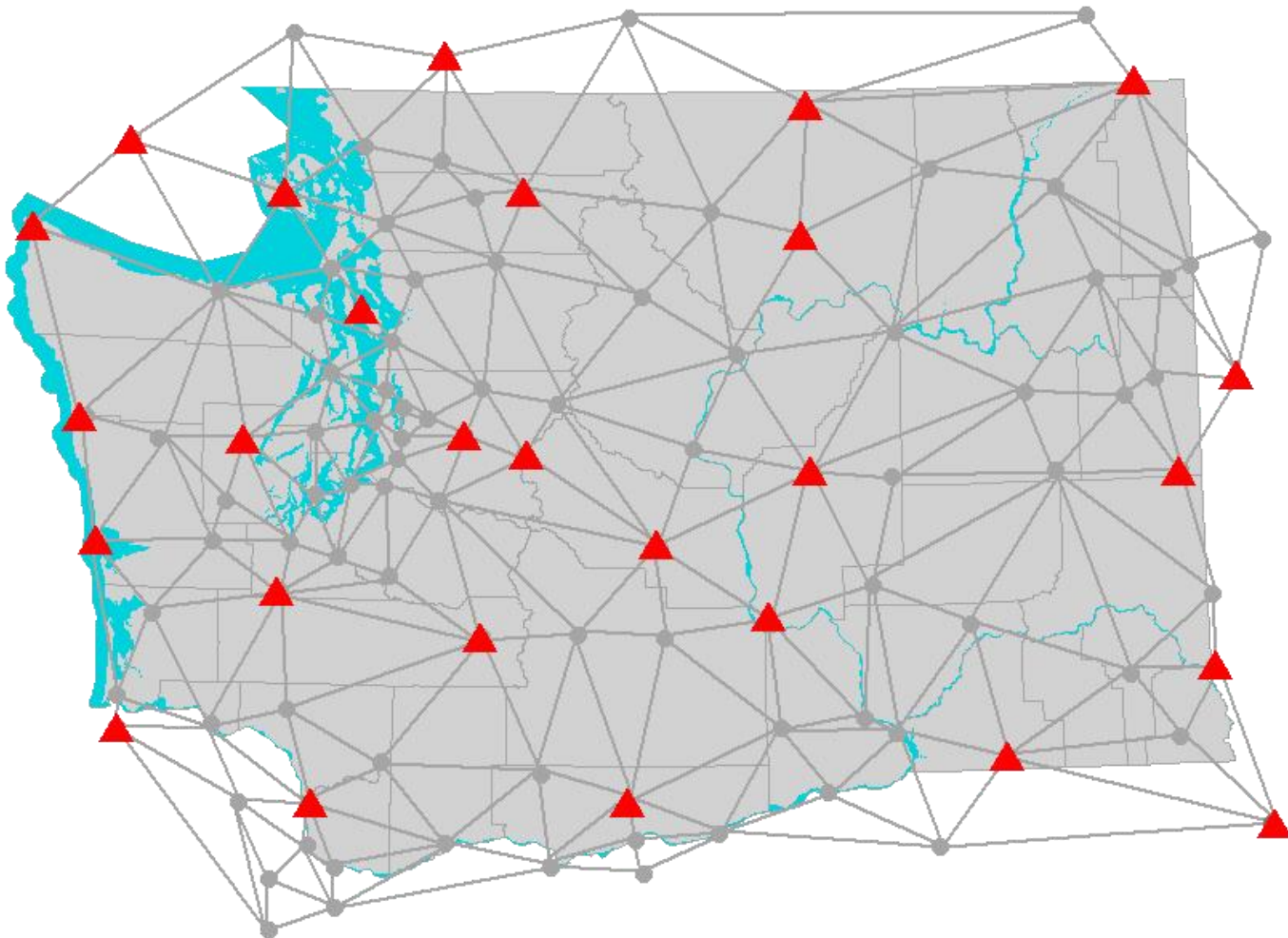
**Long Baseline
RME & PPE**

Medium Baseline RME & PPE

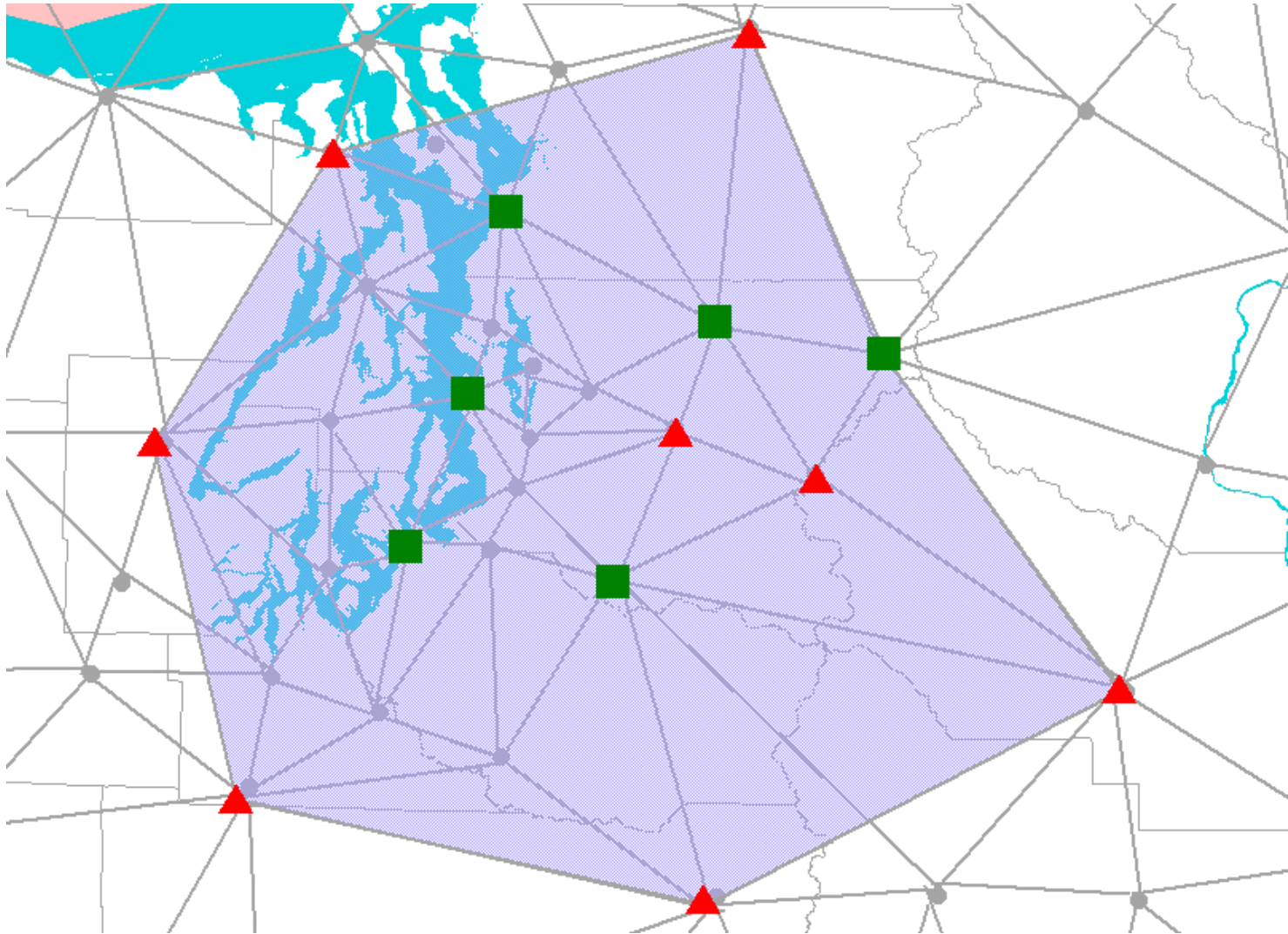




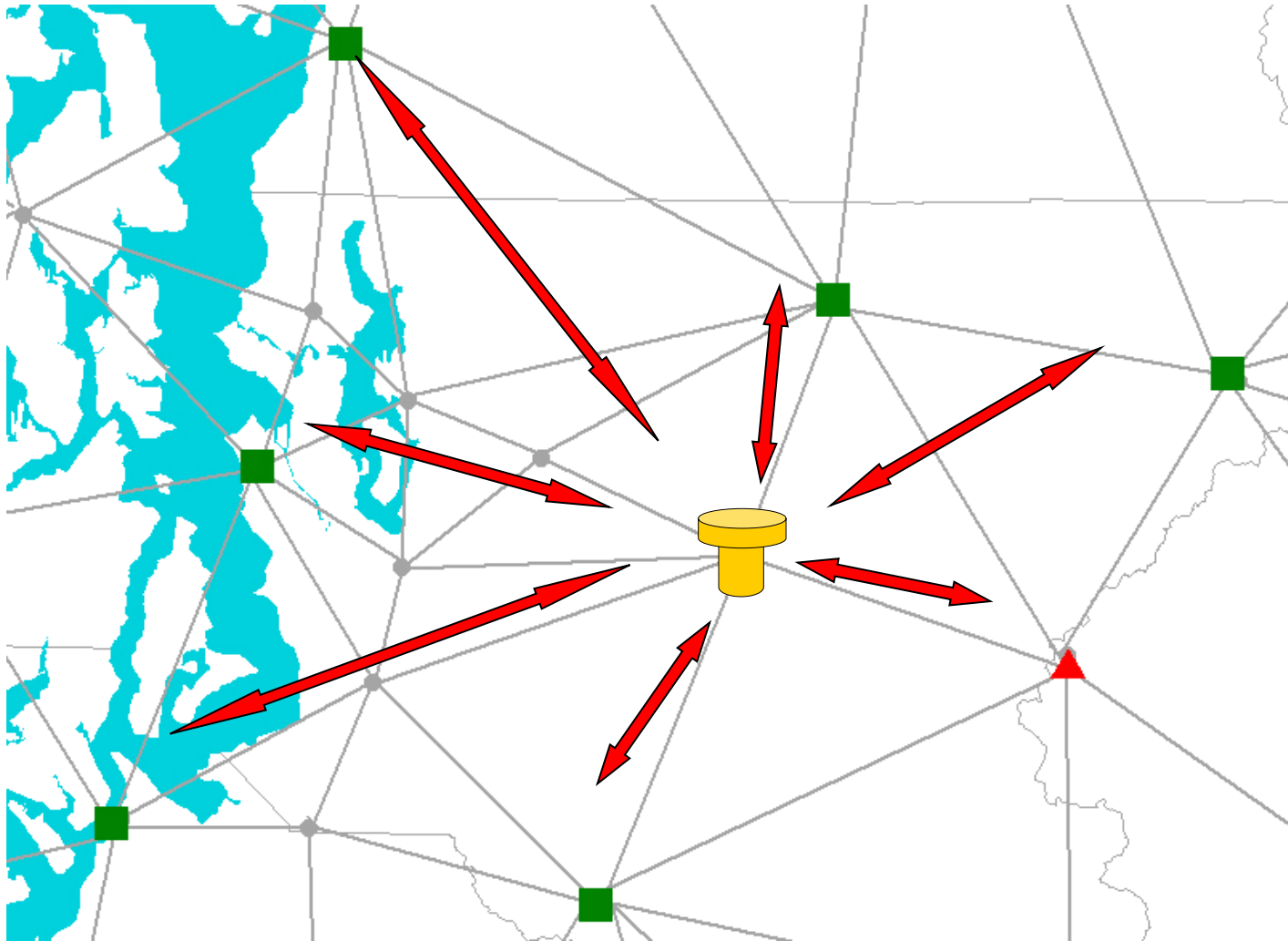
**Medium Baseline RME & PPE
Monitoring of Localized RTKE Bases**



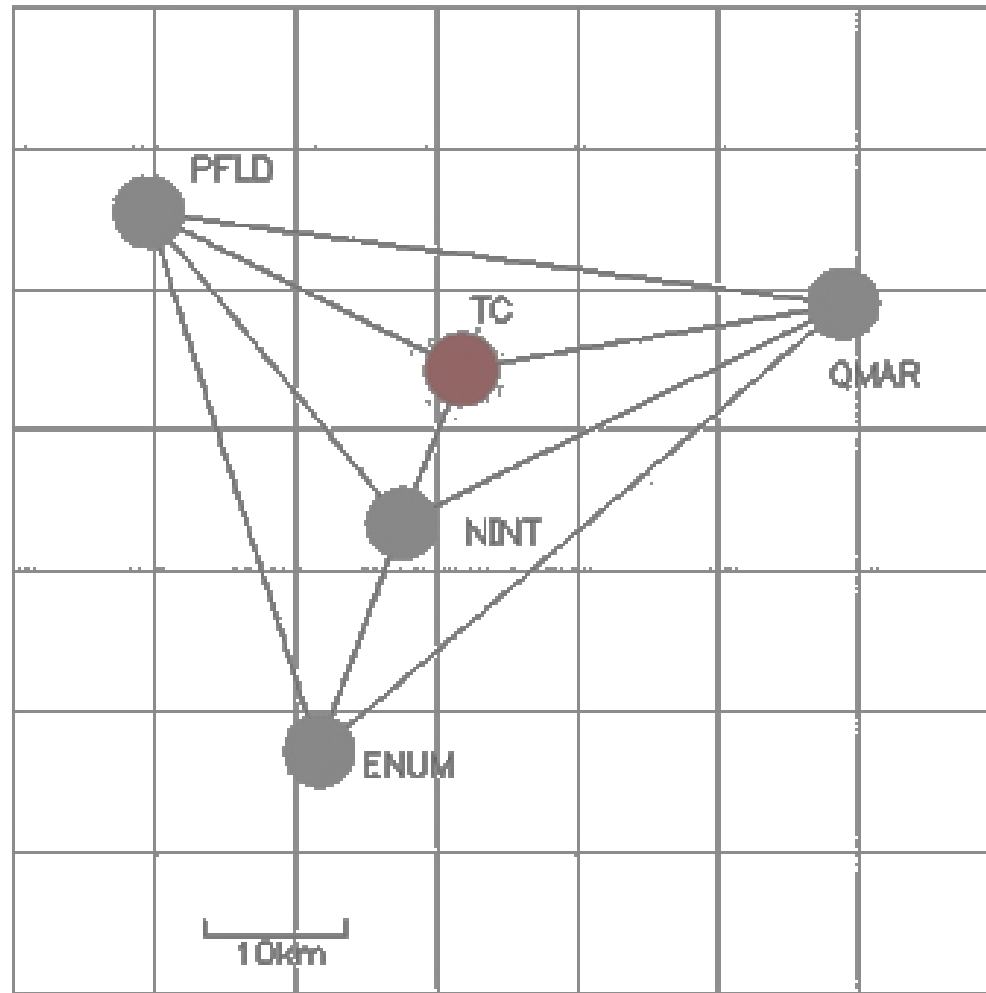
Primary Network Monitored – NGS, Academia, TIM/VRSNet



Localized Subnets Monitored in TIM/VRSNet



Localized Subnets Monitored in TIM/VRSNet



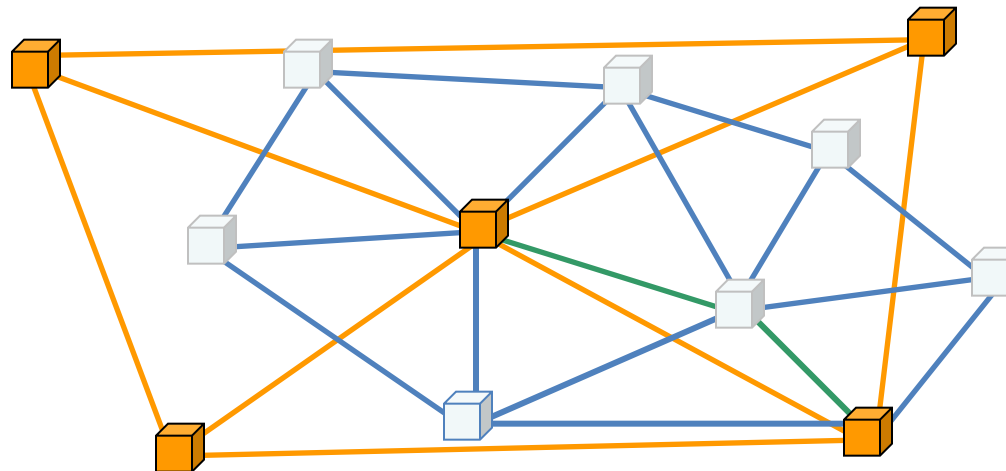
Constraining CORS for Localized Monitoring

Network Integrity – Relative Integrity

Registration to External Reference Framework

NSRS – NAD83 (CORS96) Epoch 2002.00 (et al)

NSRS – NAD83-2011 Epoch 2010.00



Select NOAA-National Geodetic Survey CORS

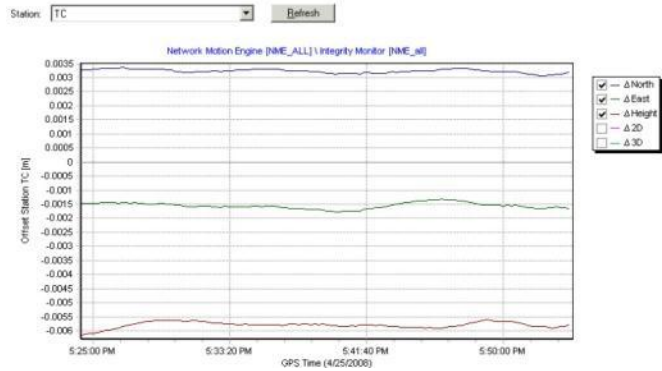
- **Registration to External Reference Framework**

IGS sites – PPS of Static Data and/or JPL PPP positions held

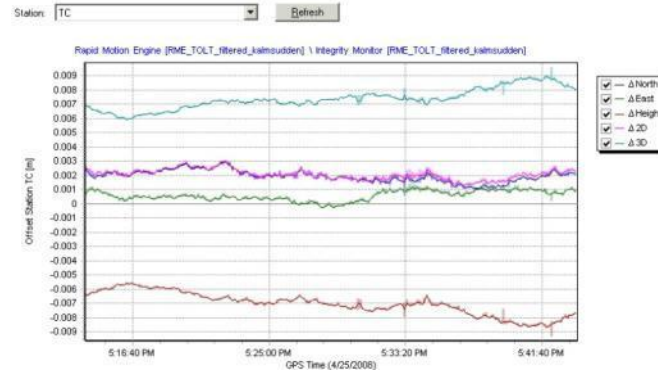


Registration to ITRF and/or SNARF utilizing Post-Processed and Rapid Motion Engine(s)

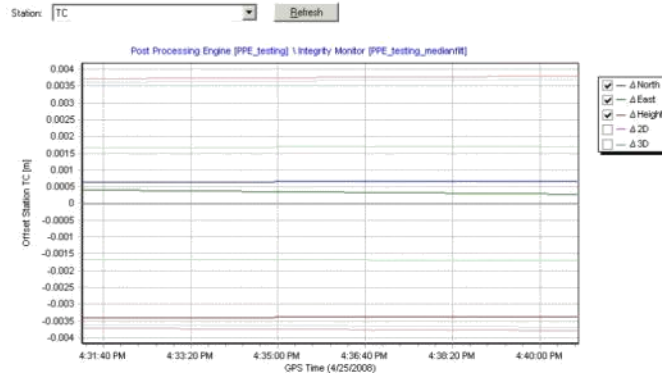




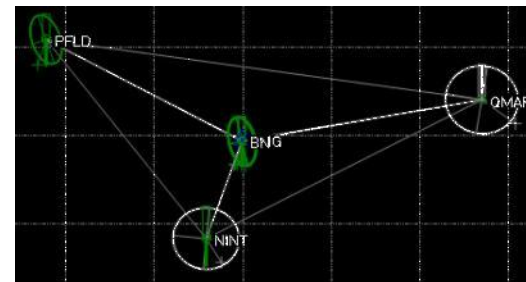
NME - Network Motion Engine



RME - Rapid Motion Engine



PPE – Post-Processing Engine



RTKE – Real-Time Kinematic Engine



WSRN Plan for NAD83-CORS96 to NAD2011 Migration

Dual System for 12-24 Months:

VRSNet – One set of servers running NAD2011 (multi-year solution)

GPSNet – One set of servers running NAD83-CORS96 Epoch 2002.00

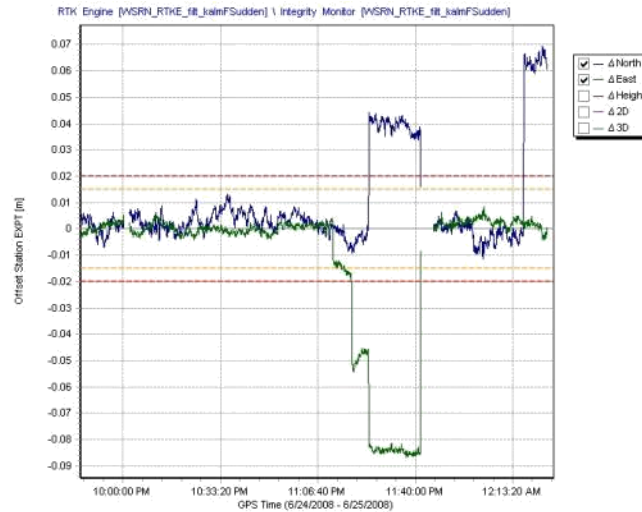


Why Should Folks be
Using RTN for
Monitoring and
Machine Control?

Structural Integrity



Dam Monitoring - Tolt



Structural Integrity Monitoring
mm Precisions in Real-Time



Ross Rockslide



520 Floating Bridge



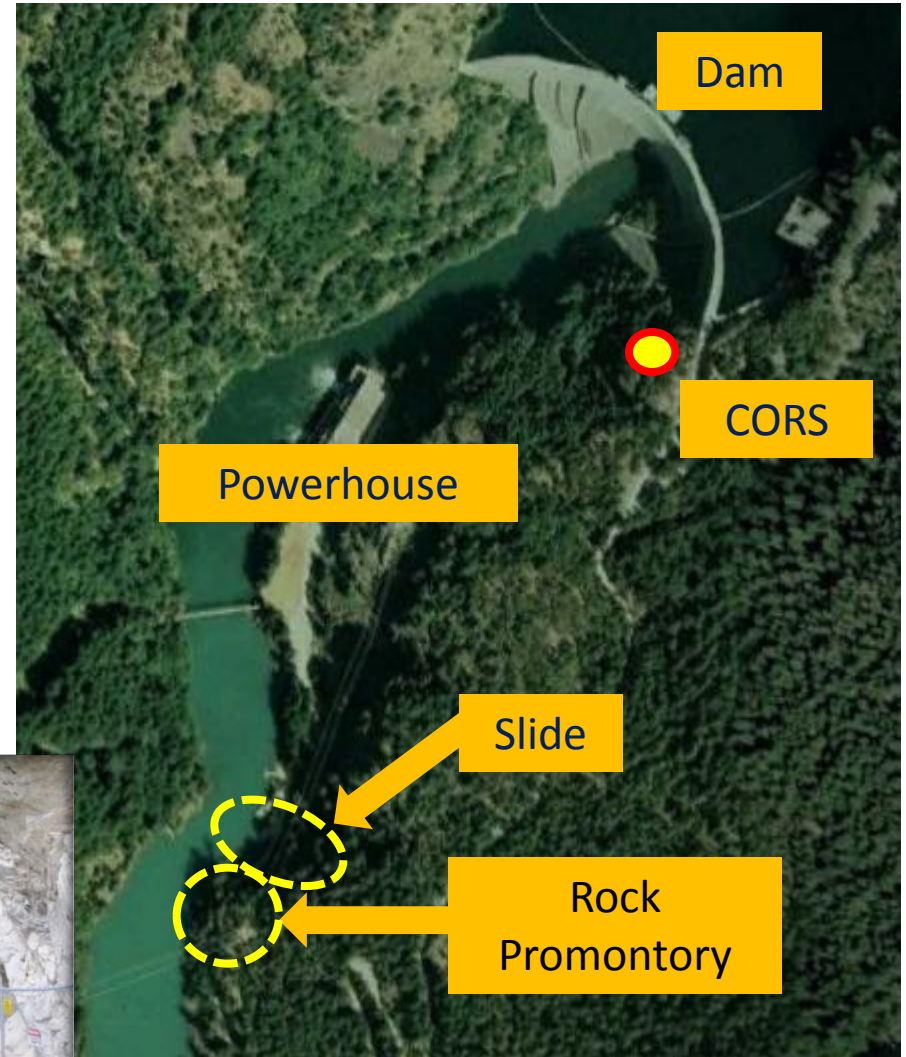
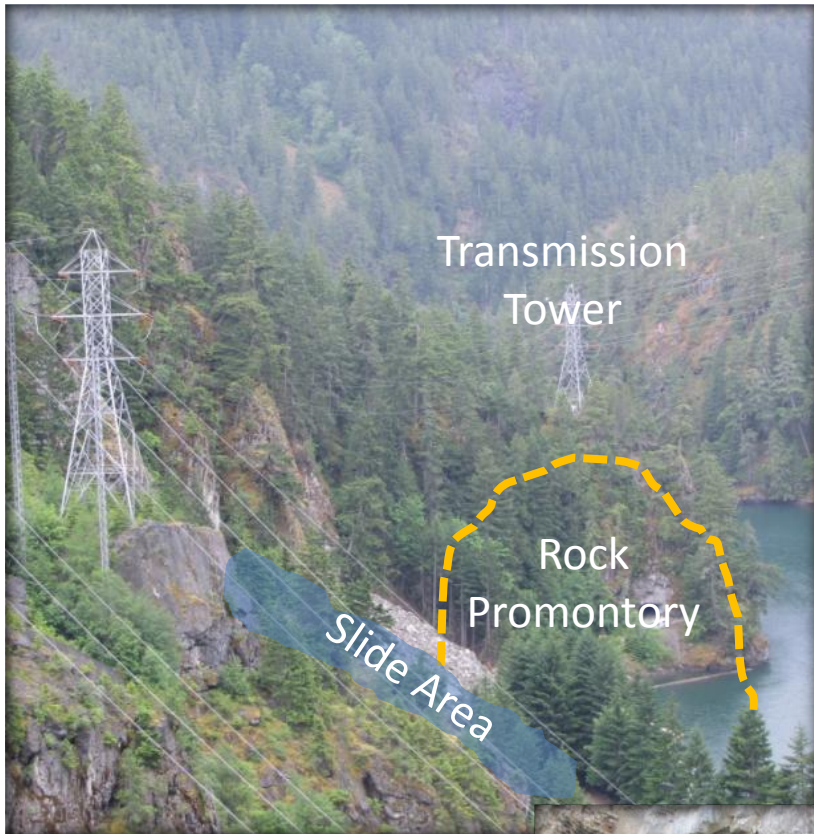
Alaskan Way Viaduct



Howard Hansen Dam



Ross Dam Rockslide



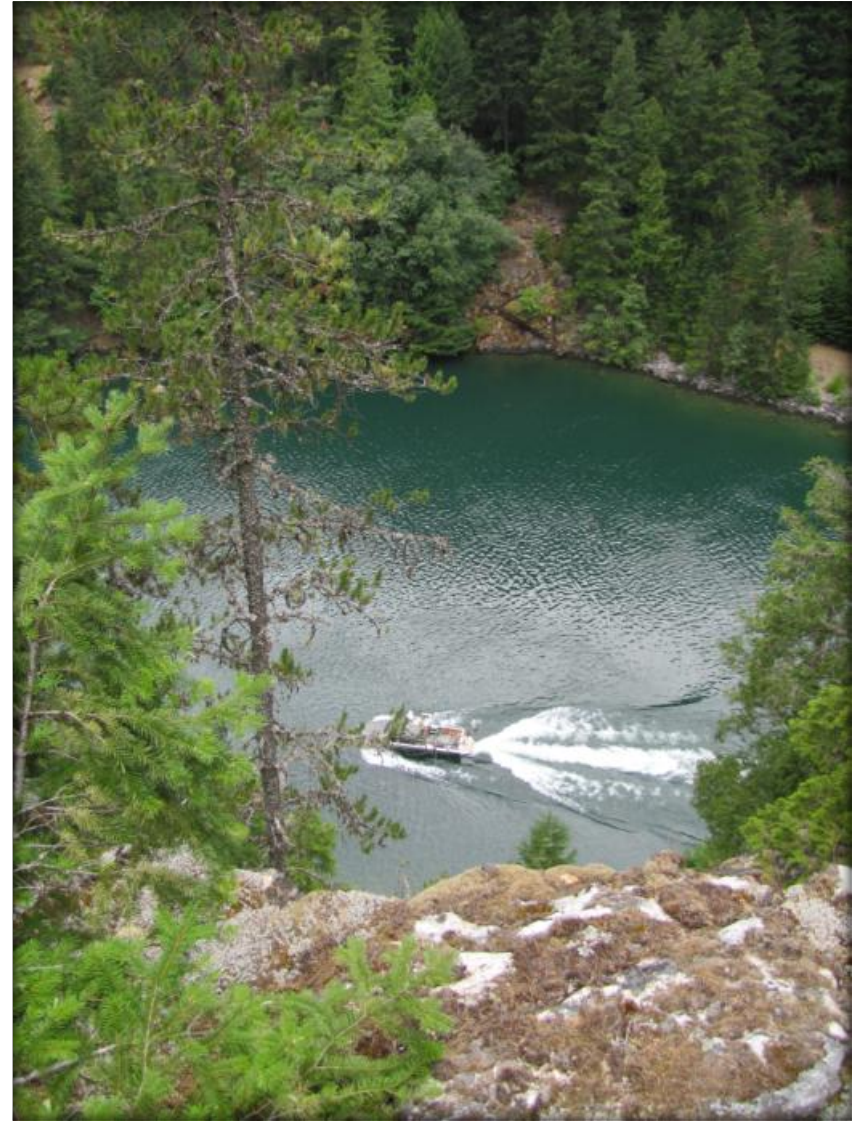
Ross Dam Rockslide



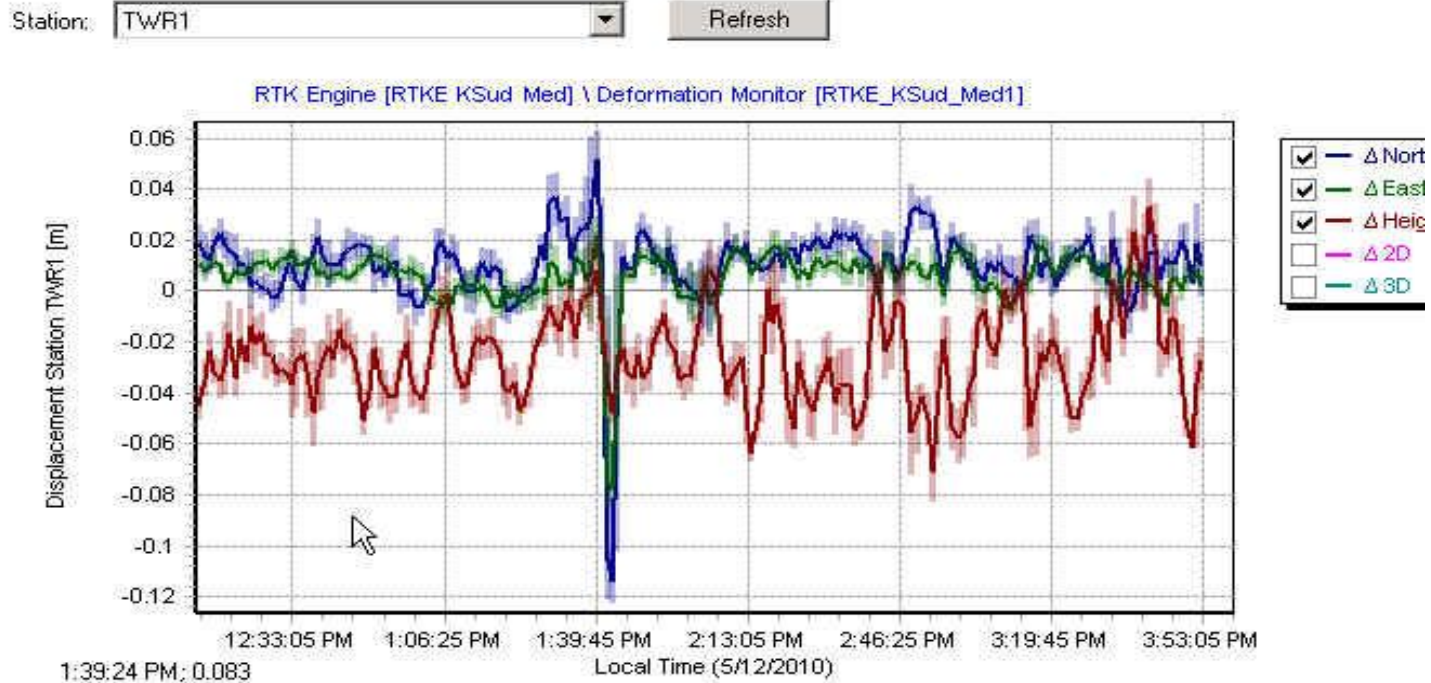
**Slide – Spring 2010
Stabilization will require blasting
and scaling**



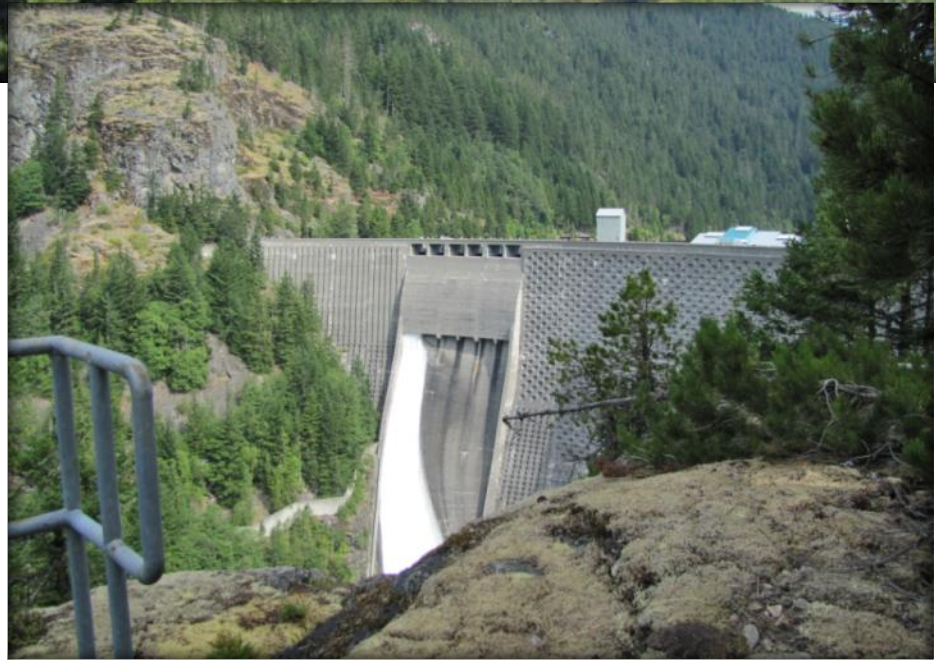
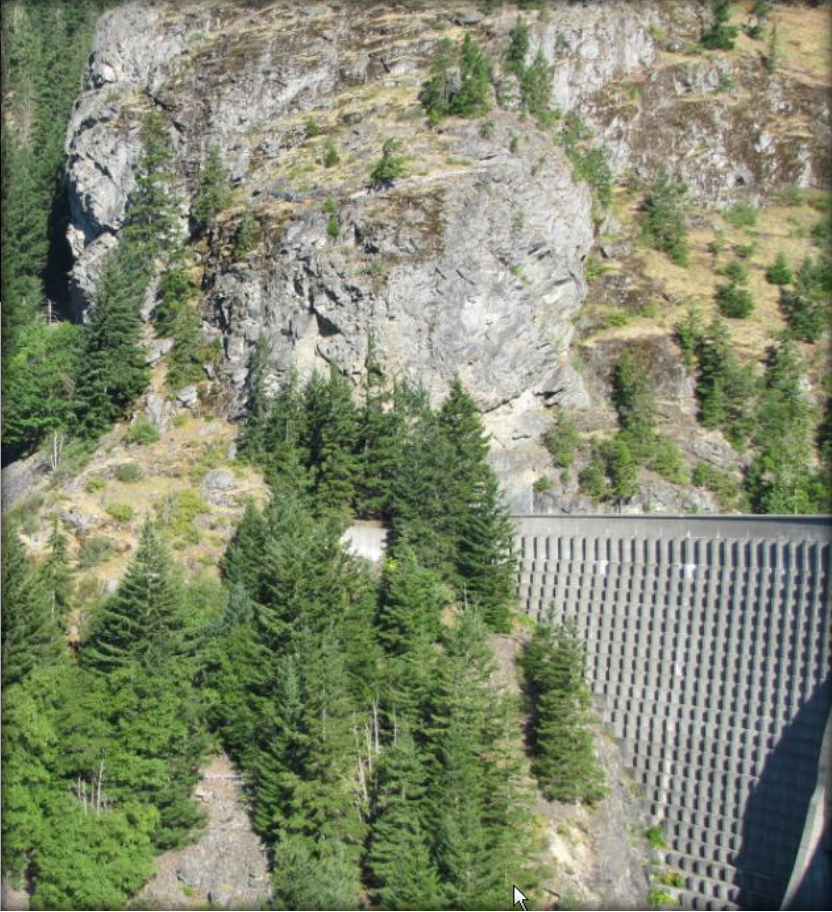
**Tower Footing on Rock Promontory
Monitored & Solar Array**



Ross Dam Rockslide



Test Blasting – May 2010



Tolt Dam



Zoned Earthfill Embankment – 61m x 300m

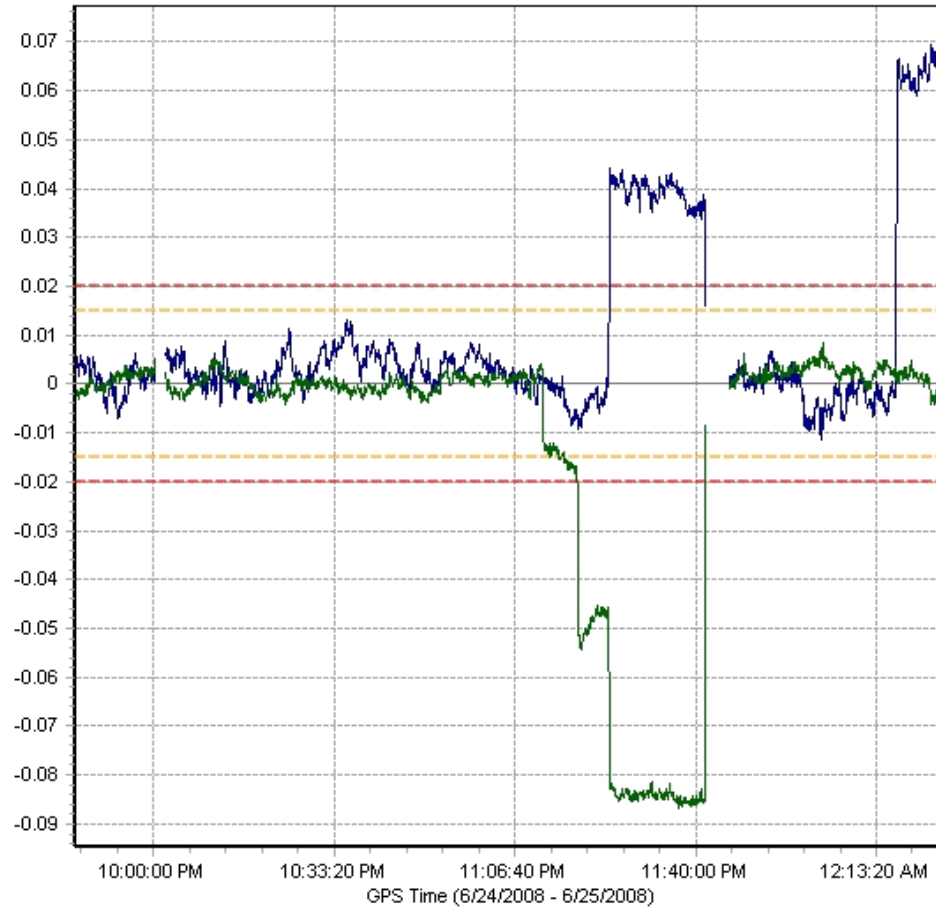
Tolt Dam

Bench Tests - 2008



Offset Station EXP1 (m)

RTK Engine [WSRN_RTKE_filt_kalmFSudden] \ Integrity Monitor [WSRN_RTKE_filt_kalmFSudden]





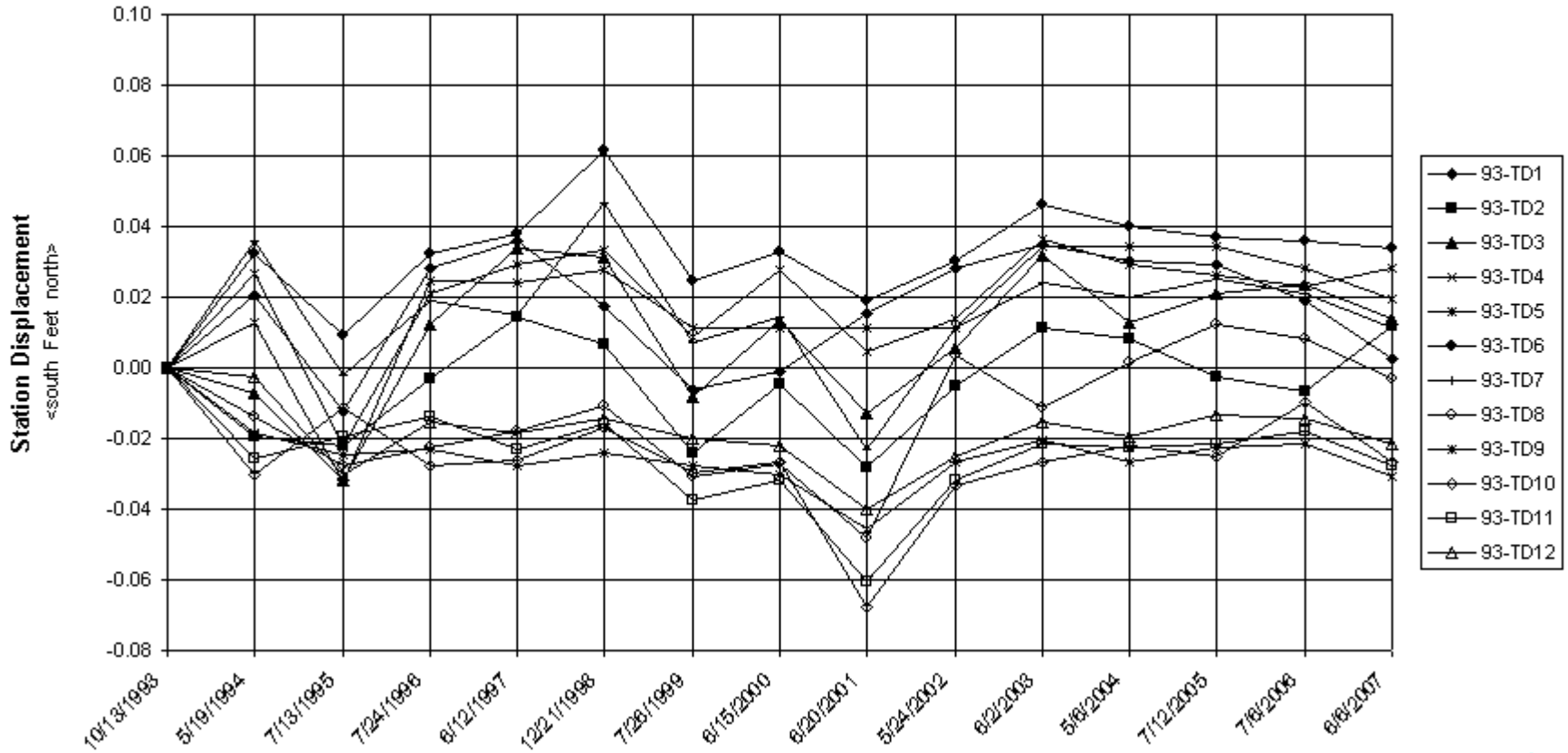
Motion Test on Translation Table



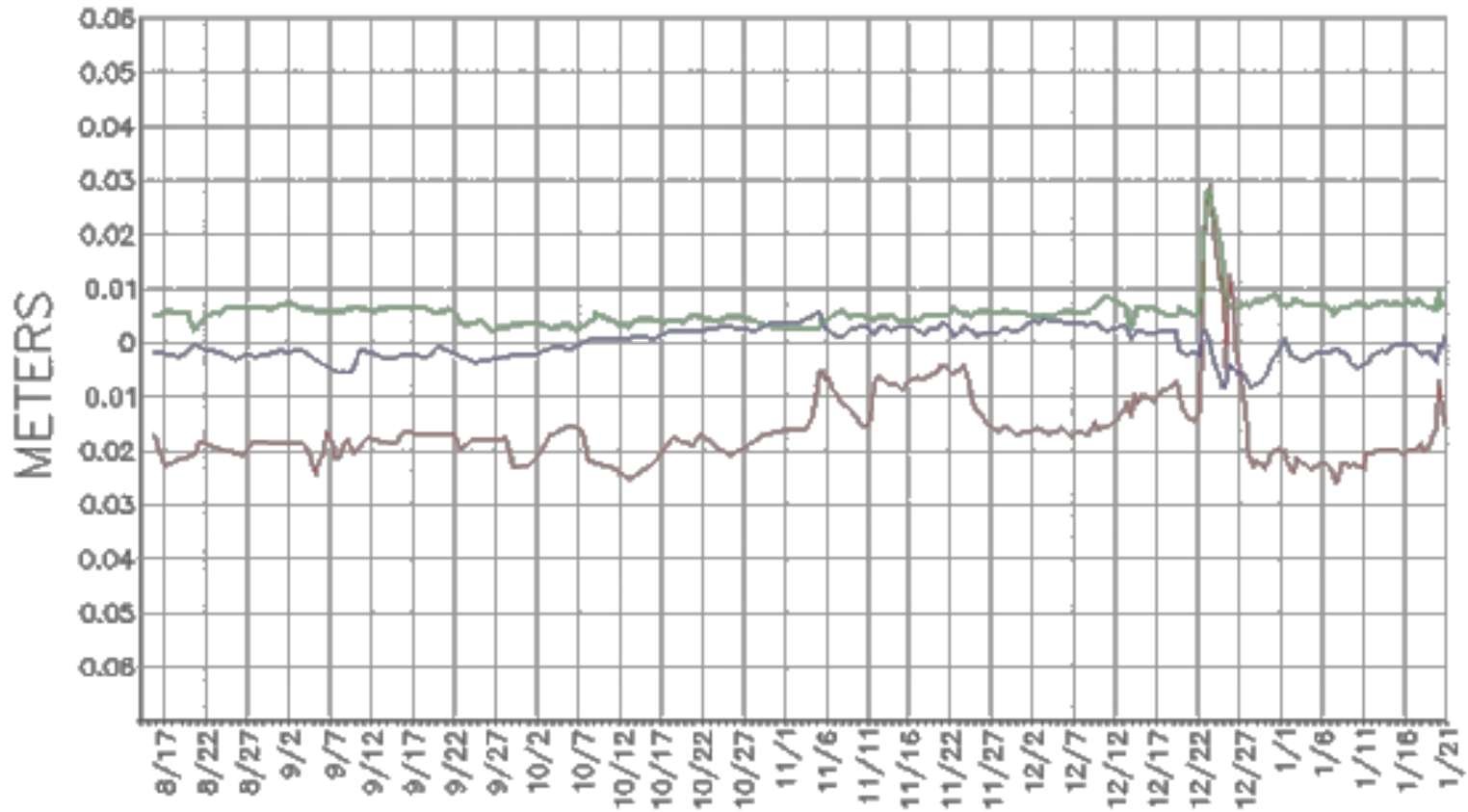
Tolt Dam

Conventional Monitoring – Annually (June)

South Fork Tolt Dam
Station Displacement

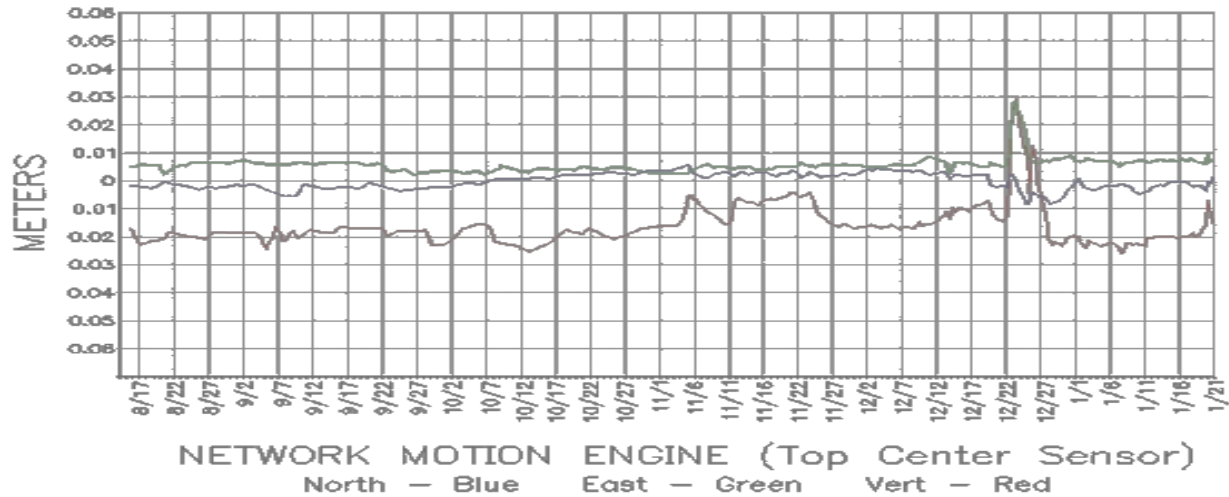
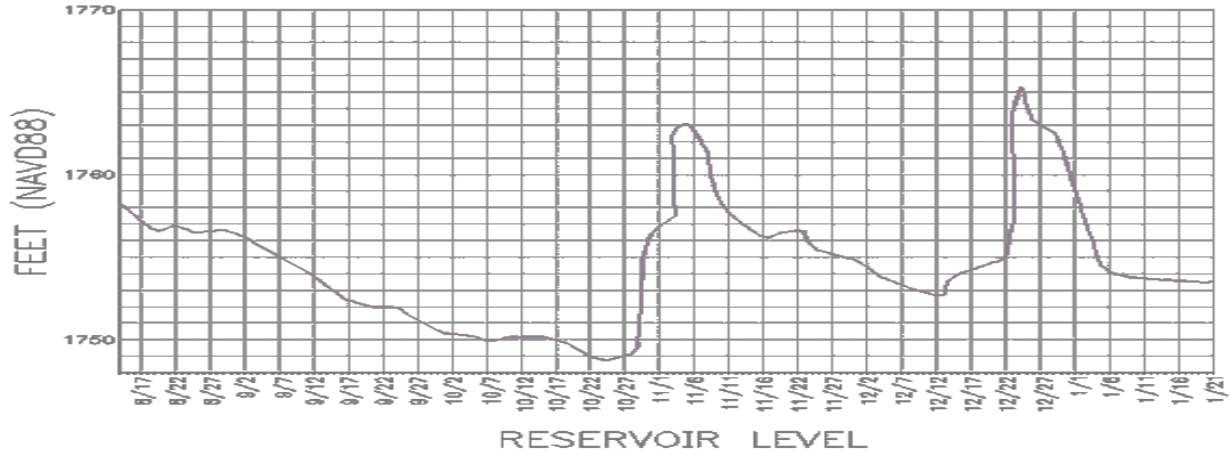


Tolt Dam



NETWORK MOTION ENGINE (Top Center Sensor)
North - Blue East - Green Vert - Red

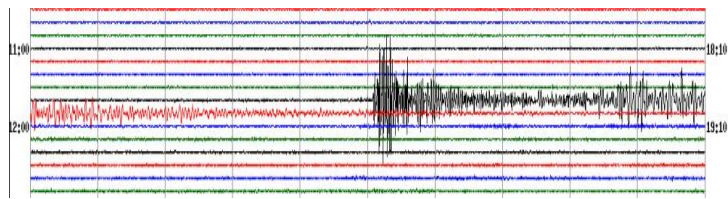
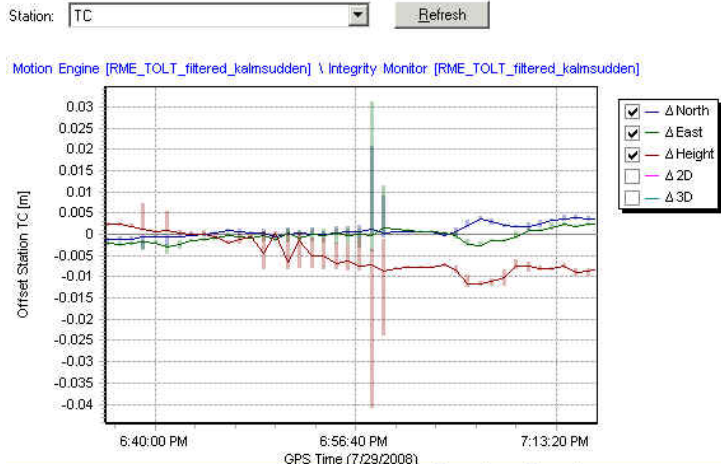
Tolt Dam



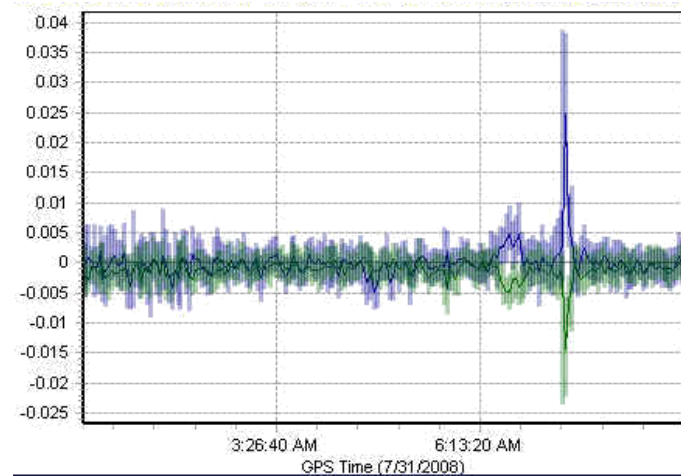
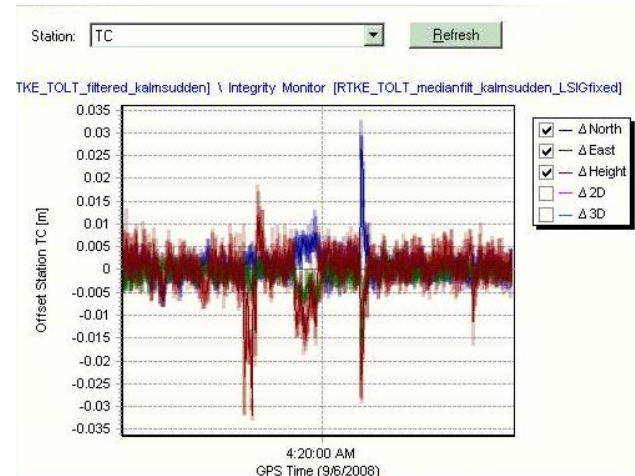
Reservoir Level and Sensor Displacement



Tolt Dam



USGS Seismograph



Possible Movement due to Seismic Events



**Howard A. Hanson Dam
Integrated Monitoring Study**

Software and Hardware Tests

**Seattle Public Utilities
May 22nd 2012**



Central
Washington
University



US Army Corps
of Engineers



Seattle
Public
Utilities

Challenges:

No Budget – Low Budget

Borrowed Equipment

Surplus Equipment

No Telecommunications Access



Triumphs:

Outstanding Support from USACE On-site crew!

Low cost radio network

Outstanding software and hardware performance

Outstanding vendor technical support



Howard Hanson Dam

- Green River, Washington State
- Legacy of Green River Flooding
- Earthen Zone-Fill Dam Completed 1961
- Cycle of Flooding Ends
- USACE Managed
- Tacoma Water – Water Purification and Distribution System
- January 2009 High Runoff and Seepage in Right Abutment. Water Released. Downstream Flooding
- Ongoing Rehab – Grout Curtain at Right Abutment
- Nov 2010 – Integrated Monitoring Study Begins

Howard Hanson Dam

Integrated Monitoring Study Goals

- Study GNSS Monitoring Capabilities
- Provide Independent Deflection Data
- Test Integrated GNSS/Optical Capabilities
- Add GNSS Sensors to Regional RTN, Earthquake Study, and Geodetic Networks
- Compare Results with Other Earthen Dams using Similar Methods (e.g, Tolt Dam)
- Test Various GNSS Motion Engines
- Geophysical Sciences Lateral Studies
- Test Alarm Thresholds
- NOT to be currently used as an alarm system

Howard Hanson Dam



NINT

18

90

SNOQ

25 km

32 km

15 km

ENUM

Howard Hanson Dam



WSRN & NGS CORS - "HAHD"

CORS - "BDRH"



Howard Hanson Dam



Exposed
Bedrock

Spillway

Dam Crest

Intake
Tower

Right Embankment

Grout Curtain

Howard Hanson Dam

BDRH



FND2



FND1



BDRD



EMBR



EMBC



EMBL



SPWY



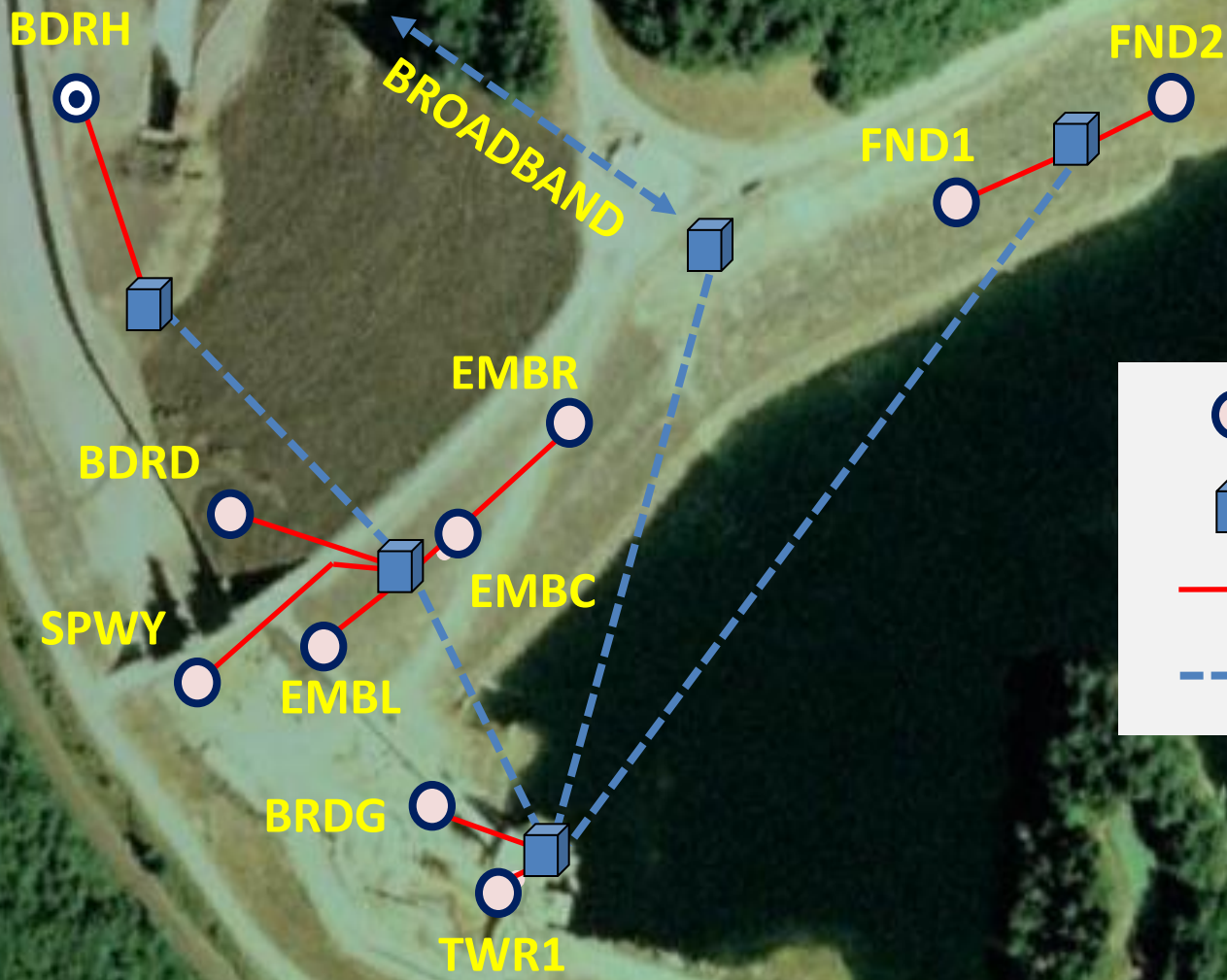
BRDG



TWR1



Howard Hanson Dam



	GNNS
	SIGNAL BOX
	COAX
	RADIO LINK

Howard Hanson Dam

BDRH



**Broadband
Comms Link**

FND1



FND2



**Post
Mount**

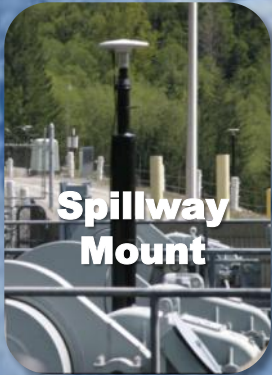


**Signal Box
Right
Embankment**



**Drill-Brace
Mount
Construction
BDRH**

EMBR



**Spillway
Mount**

SPWY



EMBC



**Bridge
Mount**

EMBL



BRDG



TWR1



**Tower
Mount**

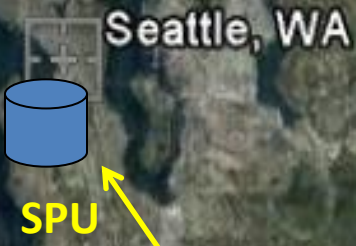


**Tower &
Bridge**

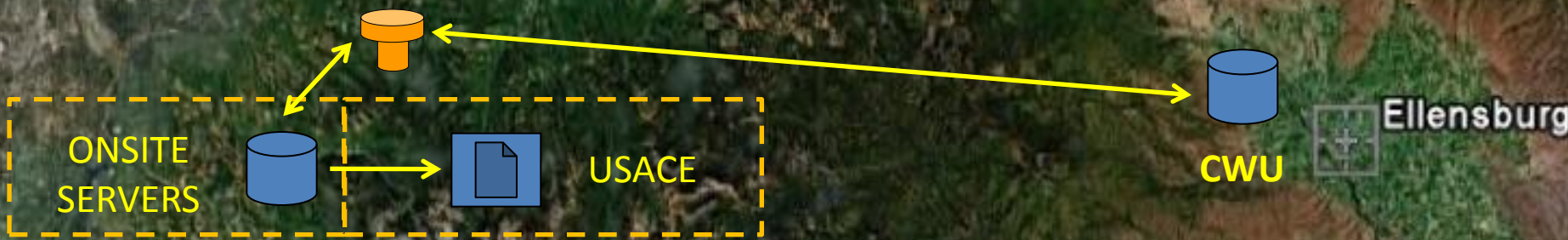


**Fish-Passage
Excavation
Next to Tower**

Howard Hanson Dam



- Processing Strategy
- Dual servers onsite
 - External comms for SPU/CWU
 - NO external connection to USACE IT
 - Science processing at CWU
 - Processing backup at SPU
 - Web Reporting Application for USACE
 - Sensor streams bi-directional to CWU/SPU



Howard Hanson Dam

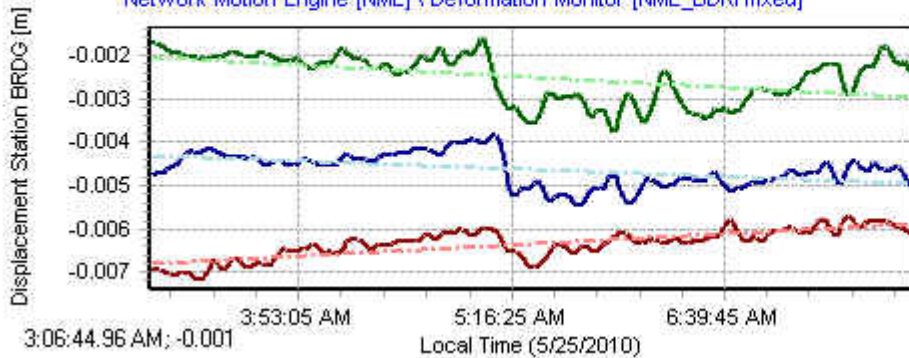
Seattle

Carnation

Station: BRDG

Refresh

Network Motion Engine [NME] \ Deformation Monitor [NME_BDRHfixed]



A minor earthquake occurred at 5:21:00 AM (PDT) on Tuesday, May 25, 2010. The magnitude 3.4 event occurred 5 km (3 miles) E of Union Hill-Novelty Hill, WA. The hypocentral depth is 6 km (4 miles).

Magnitude 3.4 - duration magnitude (Md)

Time Tuesday, May 25, 2010 at 5:21:00 AM (PDT)
Tuesday, May 25, 2010 at 12:21:00 (UTC)

45 Km

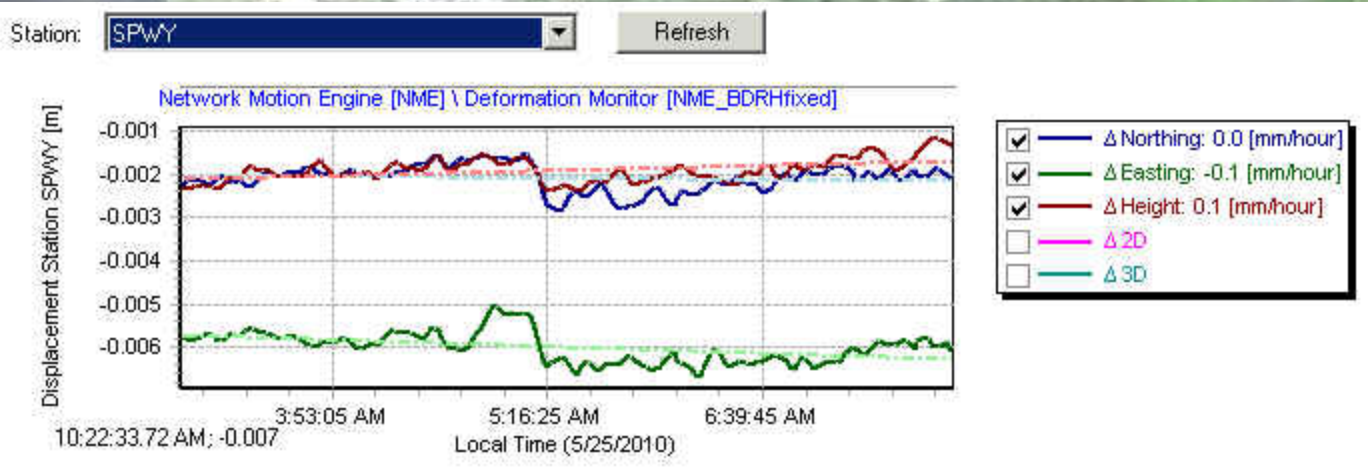
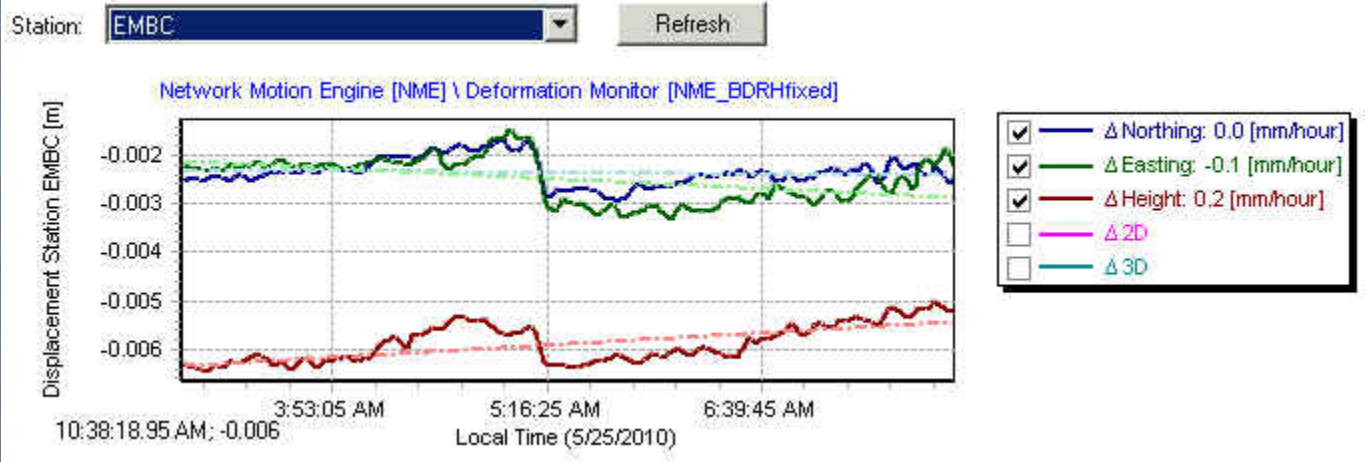
HAHD

Example- 3.4 Earthquake 45km away –May 2010

Howard Hanson Dam

Carnation

Seattle



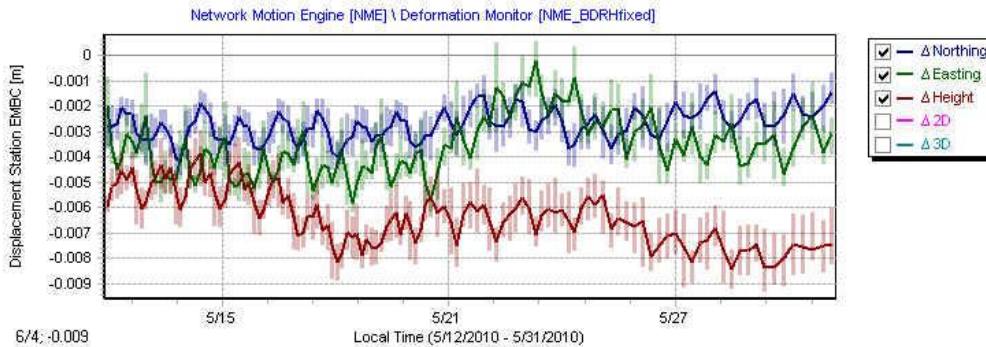
45 km

HAHD

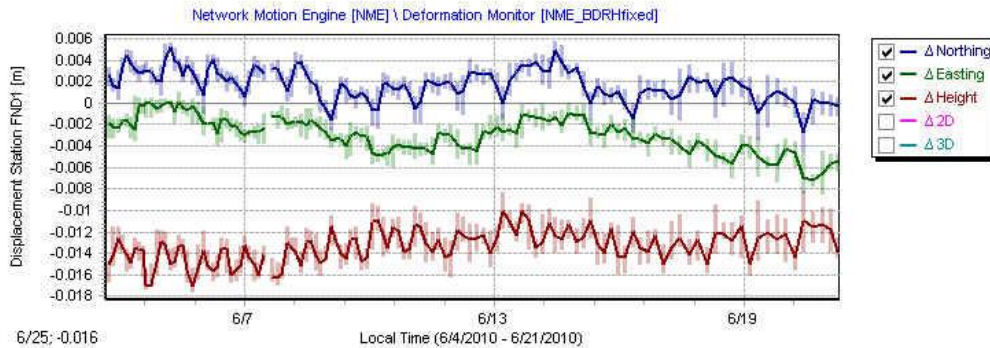
Example- 3.4 Earthquake 45km away –May 2010

Howard Hanson Dam

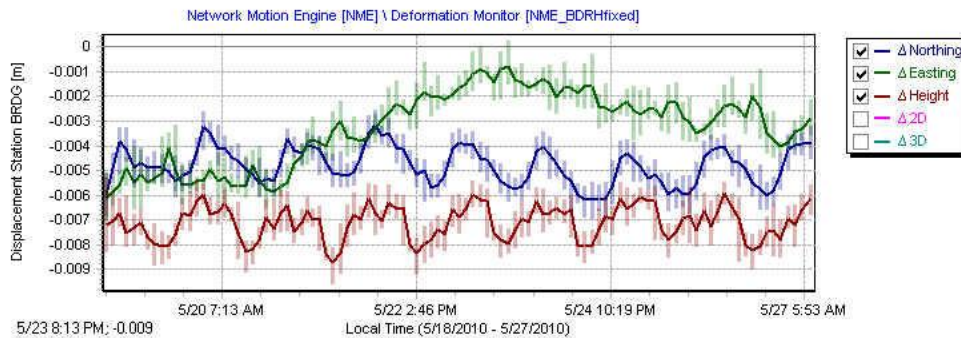
Station:



Station:



Station:



Example: Raising Pool Level May-July 2010

Excerpts from T4D User Interface

Howard Hanson Dam

Web Reporting Interface



Trimble 4D Control

> Home > Sensor Map

- Home
 - Sensor Map**
 - Change Password
- Administration
 - User Management
 - User Management
 - Create User
 - Organization Management
 - Organizations Overview
 - Create Organization
 - Sensor Map Management
 - Google Maps Key
 - Sensor Map Management
 - Health Display
 - Sensor Links
- Logout
- Trimble

Logged in as admin

Sensor Map



14 sensors

- 16
- 22
- 4
- 7
- BDRD
- BDRH
- BRDG
- EMBC
- EMBL
- EMBR
- FND1
- FND2
- SPWY
- TWR1

Howard Hanson Dam Web Reporting Interface

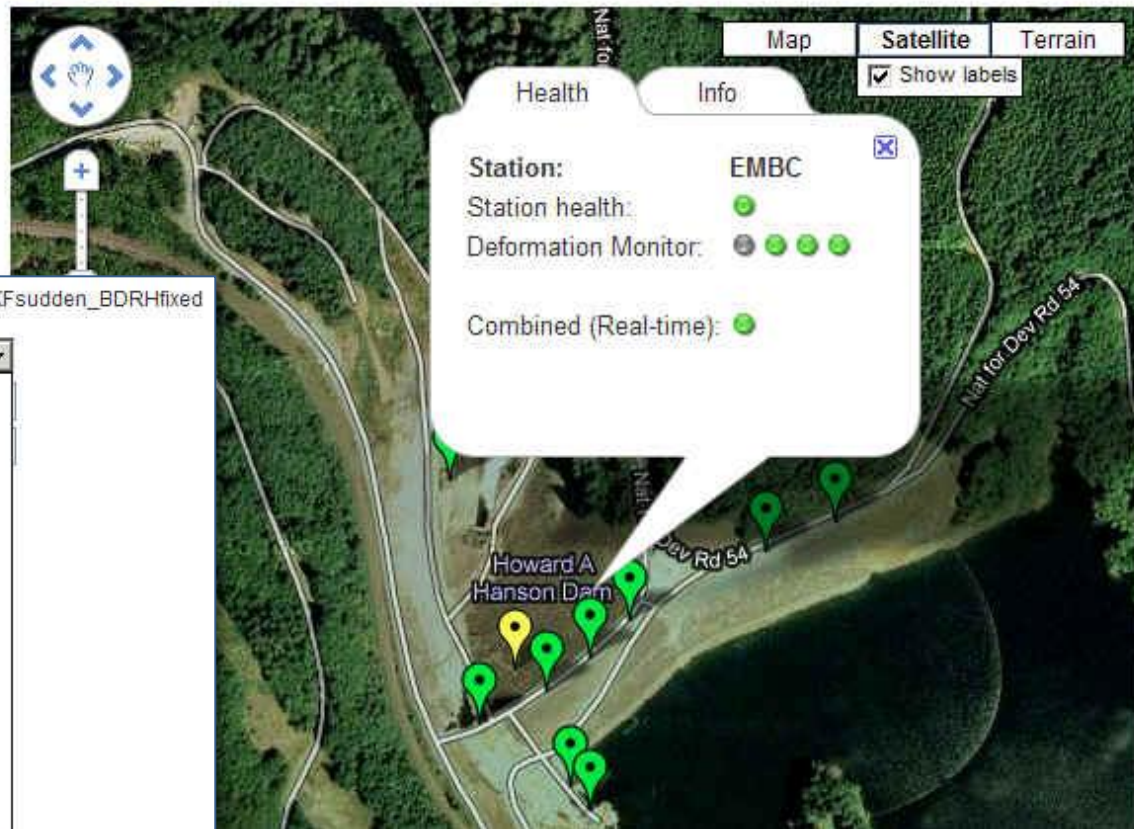


Trimble 4D Control

> Home > Sensor Map

- Home
 - Sensor Map
 - Change Password
 - Administration
 - User Management
 - User Management
 - Create User
 - Organization Management
 - Organizations Overview
 - Create Organization

Sensor Map



14 sensors

- 16
- 22
- 4
- 7
- BDRD
- BDRH
- BRDG
- EMBC**
- EMBL
- EMBR
- FND1
- FND2
- SPWY
- TWR1

Deformation Monitor Configuration: RTKE_KFsudden_BDRHfixed

Time span: Custom

From:

To:

Generate

- Last 1 hour
- Last 3 hours
- Last 6 hours
- Last 12 hours
- Last 24 hours
- Yesterday
- Last 48 hours
- Last 3 days
- Last 5 days
- Last 7 days
- Last 14 days
- Last 30 days
- Last 60 days
- Last 90 days
- Last 180 days
- Last year
- Last 2 years
- Custom**

Trimble
Logged
UK

Alarm Modules

Operational Alarms

System Elements:

Unavailable
Performance Thresholds

System Events:

Conditions Change
Conditions Persist
Conditions Return to Normal

System Triggers:

Email
SMS
Batch/Scripts
Reboot/Power Management

Alarm Modules

Performance Alarms

Warning Thresholds:

X, Y, Z
Velocity
2D & 3D
Condition Persists

Alert Thresholds:

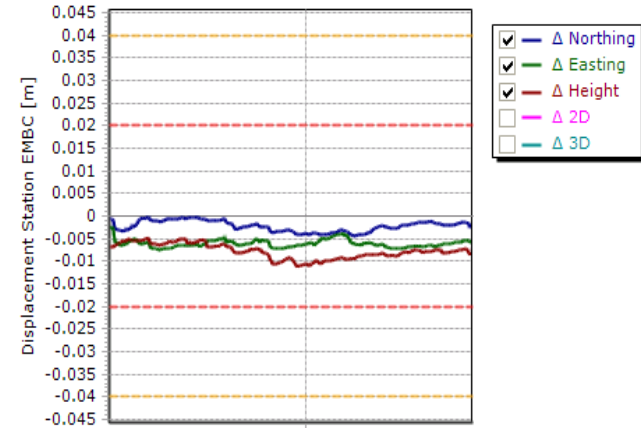
X, Y, Z
Velocity
2D & 3D
Condition Persists

Disarm Thresholds:

X, Y, Z
Velocity
2D & 3D
Condition Persists

Actions:

Email, SMS
Batch/Scripts
Controls/Power Management



Properties	
Minimum epochs	10
Disarm Thresholds	
3- σ Northing [m]	0.060
3- σ Easting [m]	0.060
3- σ Height [m]	0.060
3- σ 2D [m]	0.060
3- σ 3D [m]	0.060
3- σ Velocity northing [mm/day]	0.500
3- σ Velocity easting [mm/day]	0.500
3- σ Velocity height [mm/day]	1.000
3- σ Velocity 2D [mm/day]	0.700
3- σ Velocity 3D [mm/day]	1.200
Warning Thresholds	
Δ Northing [m]	0.040
Δ Easting [m]	0.040
Δ Height [m]	0.040
Adjustment	

Howard Hanson Dam

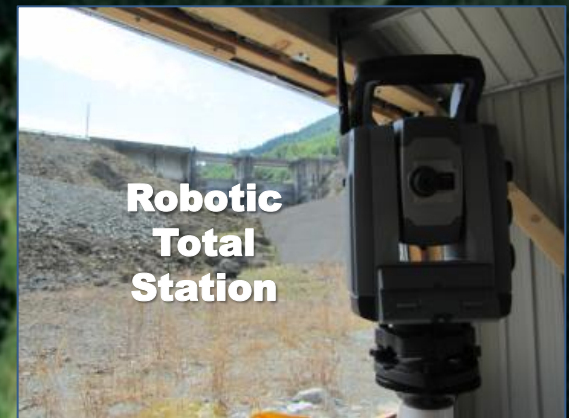
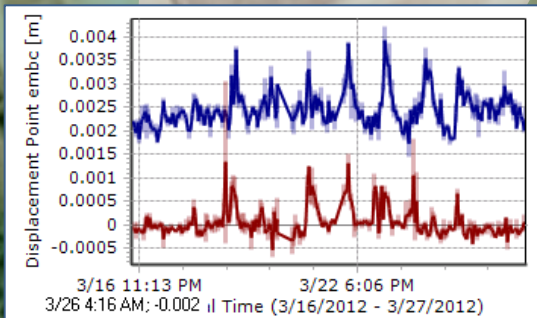
Optical/GNSS Integration

BACKSITE

TOTAL
STATION



GNSS
Antenna &
Target for
Control



Robotic
Total
Station

Optical/GNSS Integration

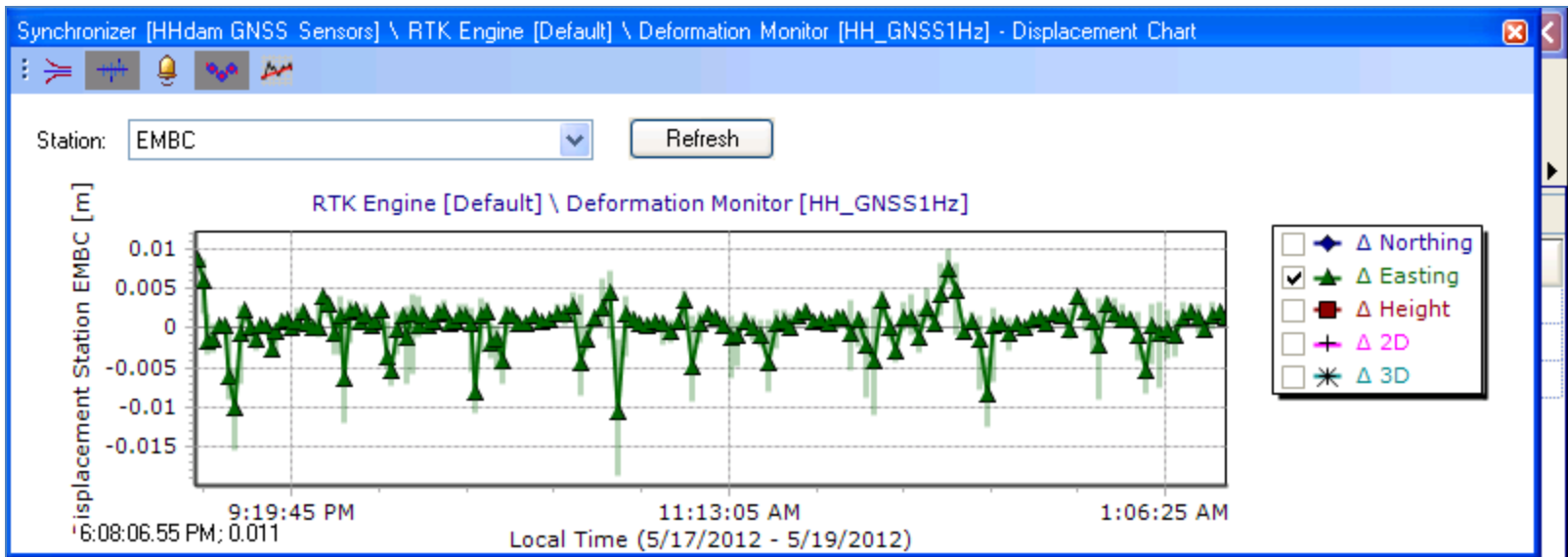


Internet Camera S
TV-I

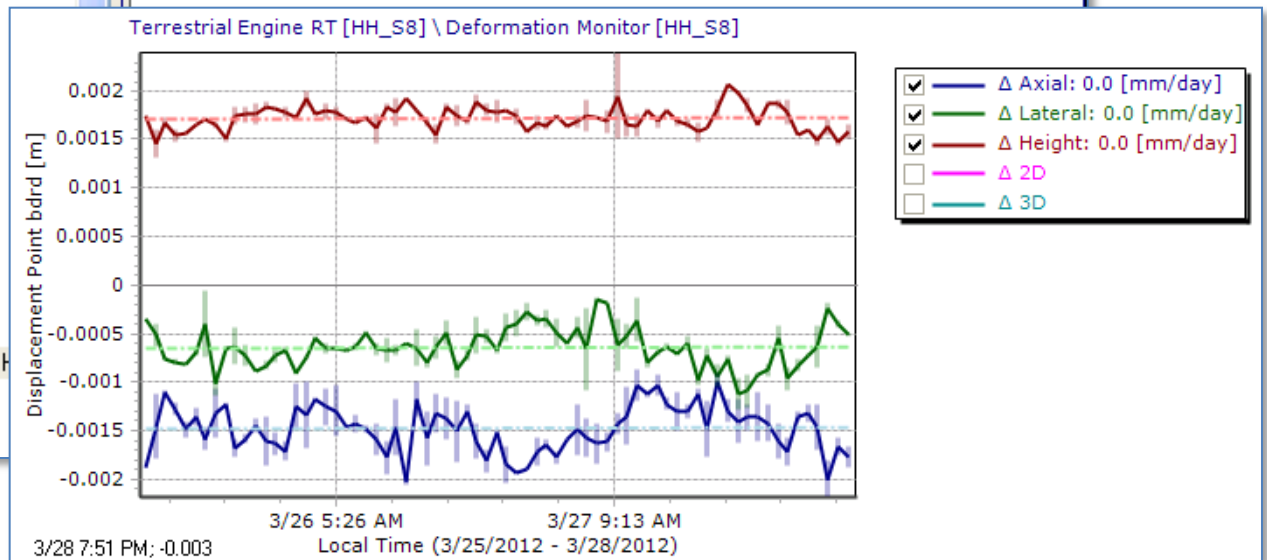
Location: 2007/01/21 19



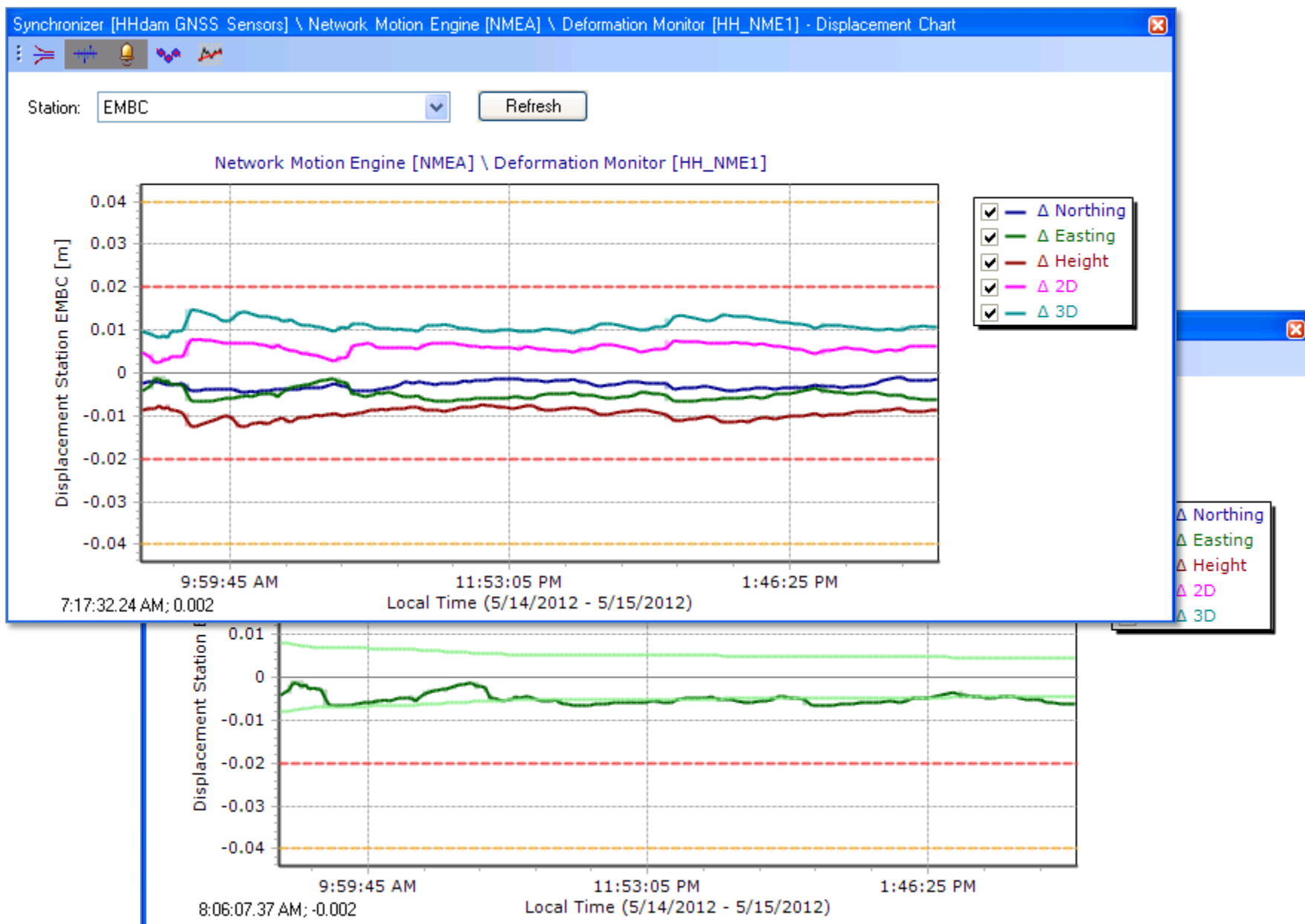
Motion Engines



- Epniemens manager [Default]
- Instrument Manager [Default]
- Data Collector [HH_S8]
- Integrated Survey Engine [Default]
- Deformation Monitor [HH_S8 GNSS]
- Integrated Survey Engine [IE_PP_S8]
- Deformation Monitor [IE_PP_H8]
- Post Processing Engine [Default]
- Deformation Monitor [Config5]
- Synchronizer [HHdam GNSS Sensors]
 - Network Motion Engine [NMEA]
 - Deformation Monitor [HH_NME1]
 - RTK Engine [Default]
 - Deformation Monitor [HH_GNSS1Hz]
 - Terrestrial Engine RT [HH_S8]
 - Deformation Monitor [HH_S8]

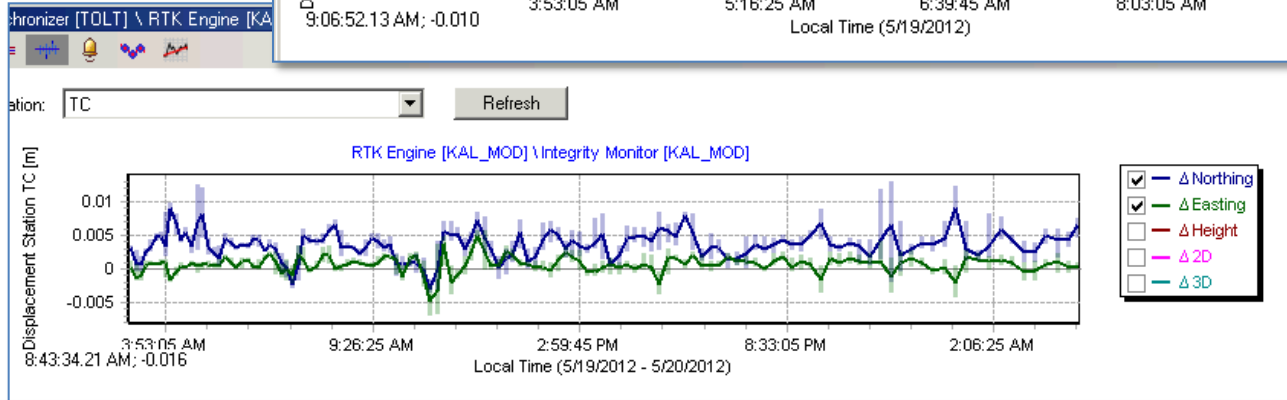
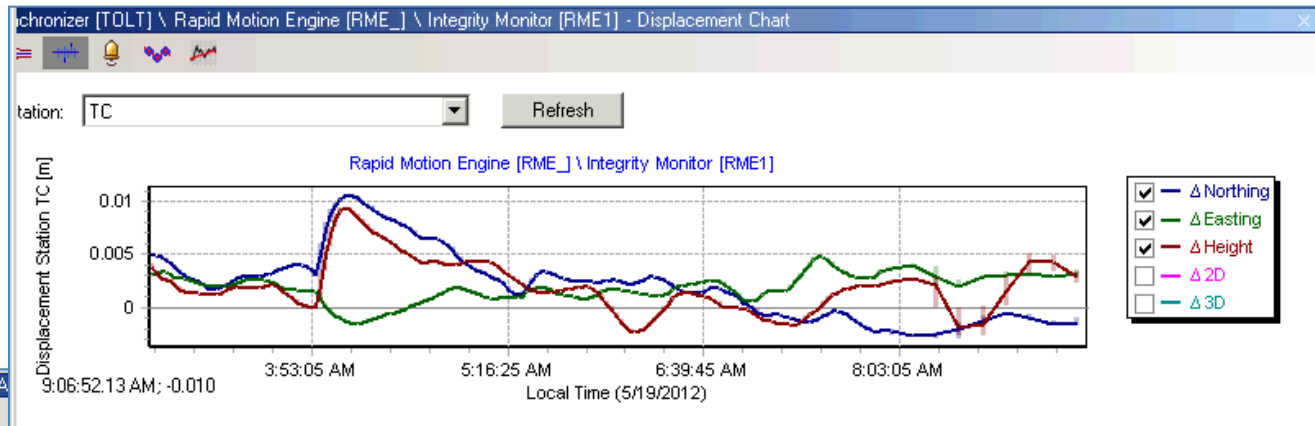


Motion Engines

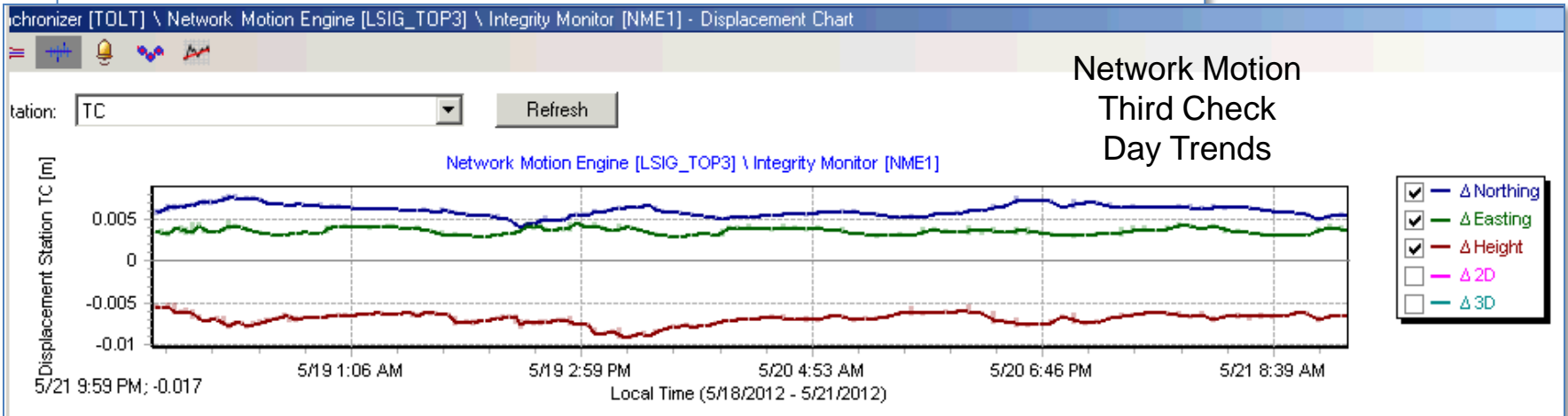


Motion Engines

Sudden Motion
First Check
Minutes Trends

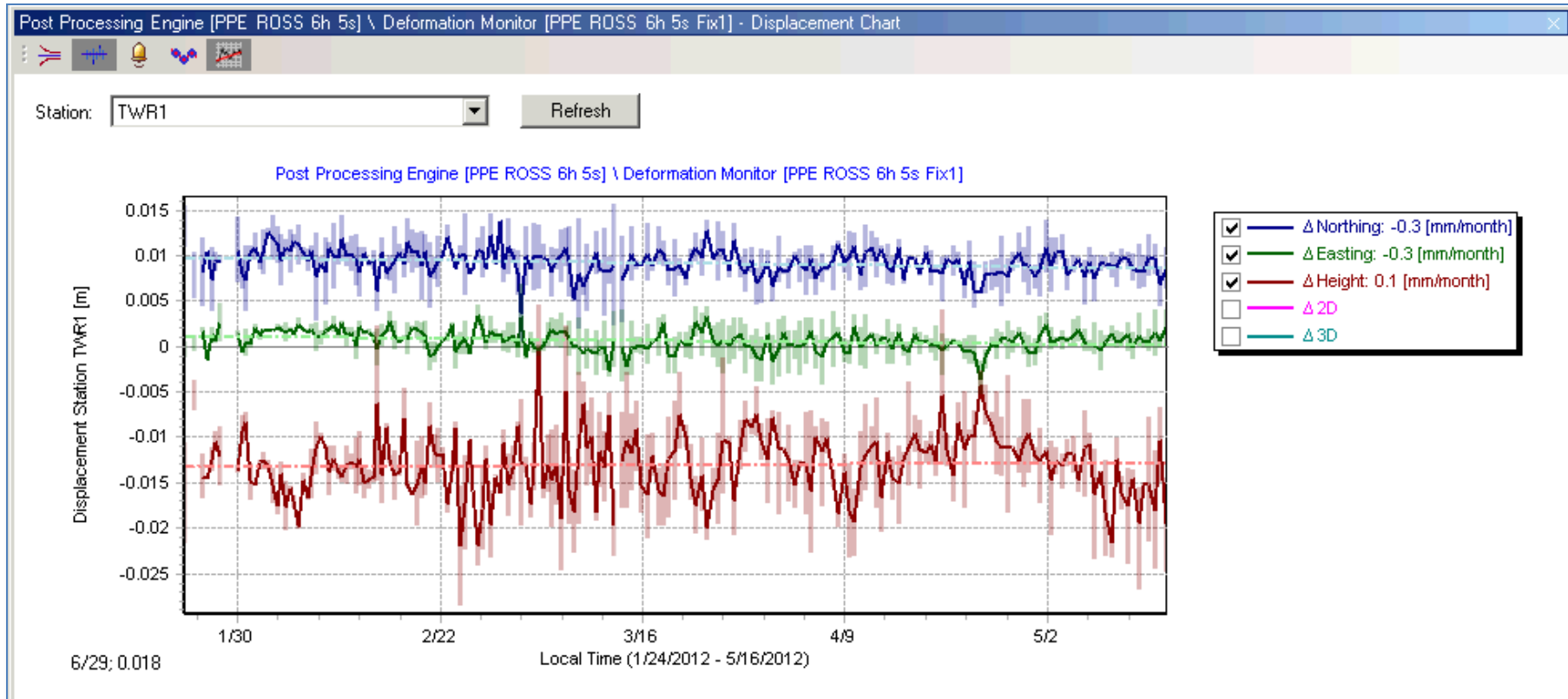


RTK Motion
Second Check
Hour Trends



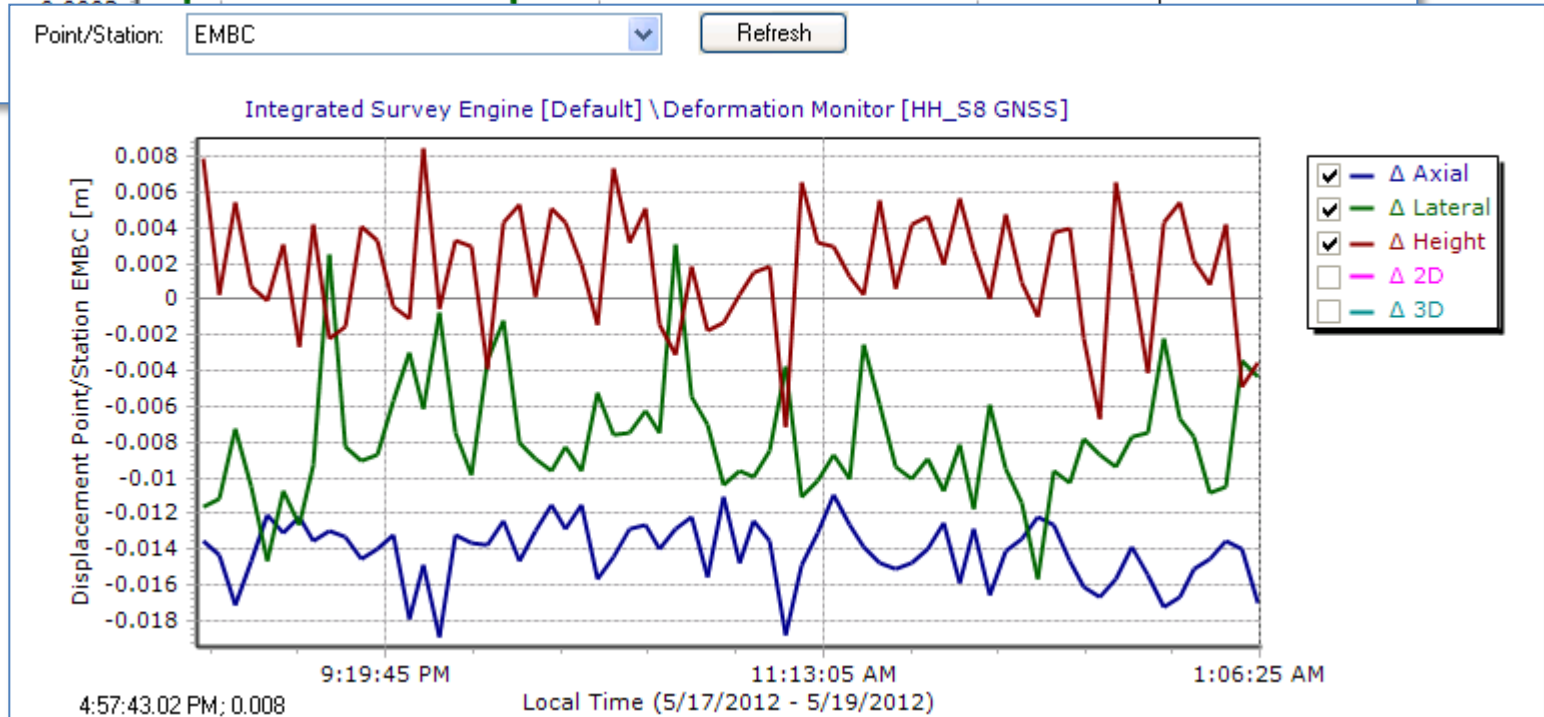
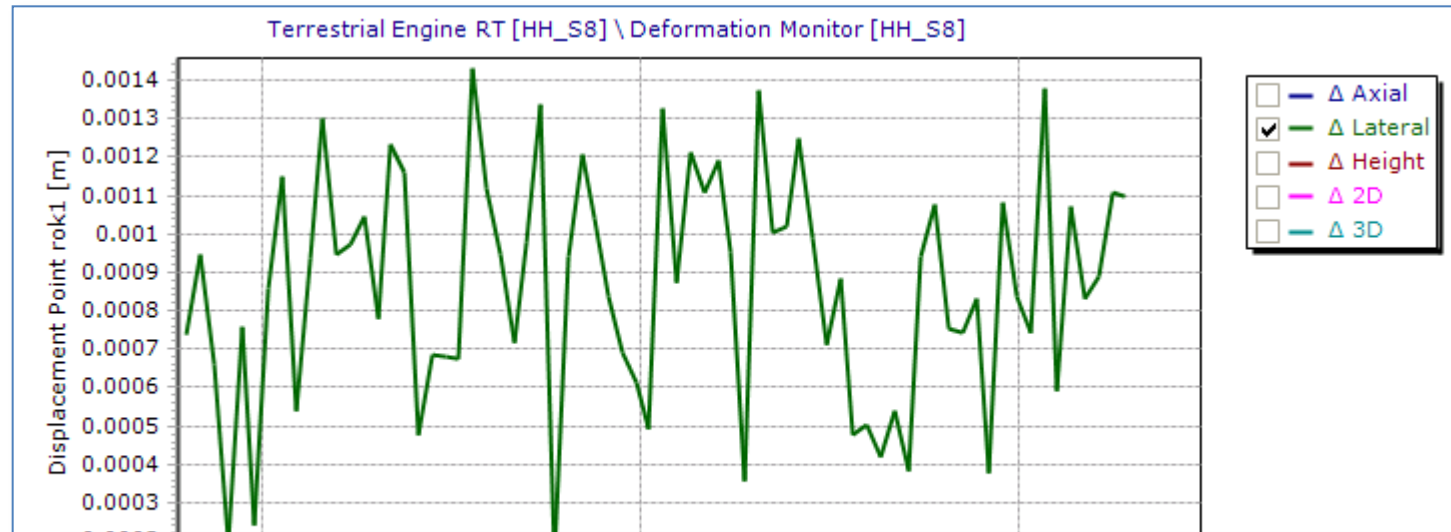
Network Motion
Third Check
Day Trends

Motion Engines



Post-Processing Engine
Long-Term Trending

Motion Engines - Optical



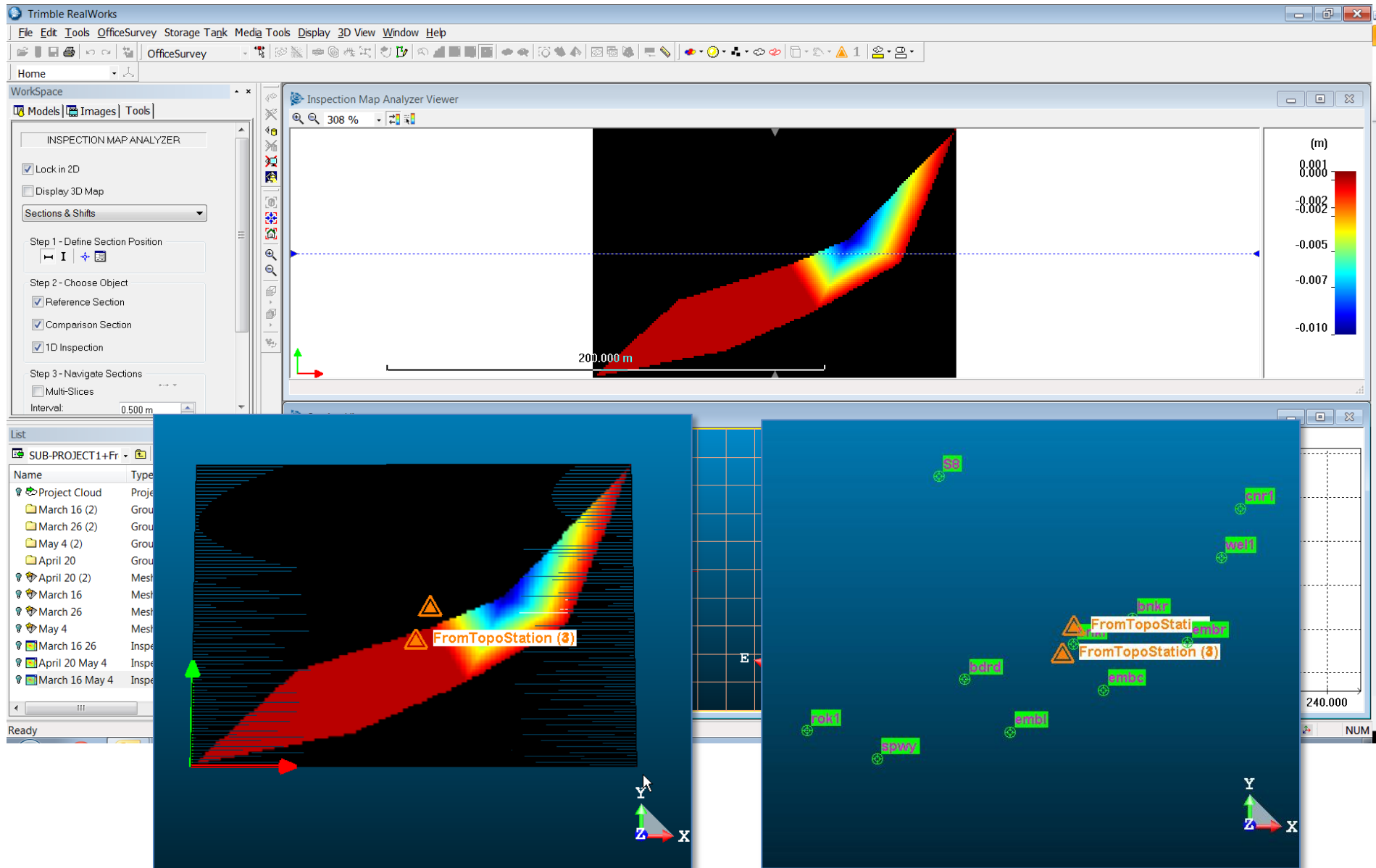
Motion Engines

Engine	Filter	Reaction time for 50% of movement	Reaction Time 100% of movement
RTK	Unfiltered	-	0 sec
RTK	Weighted mean (1 min)	-	1 min
RTK	Kalman sudden	-	30 sec
RTK	Kalman moderate	-	6 min
Rapid Motion	unfiltered	1 sec	> 15 min
Rapid Motion	Weighted mean (1 min)	45 sec	> 15 min
Rapid Motion	Kalman sudden	5-10 sec	> 15 min
Rapid Motion	Kalman moderate	5 min	> 30 min
Network Motion	N/A	2 h	12 – 24 h

Motion Engines - Filters

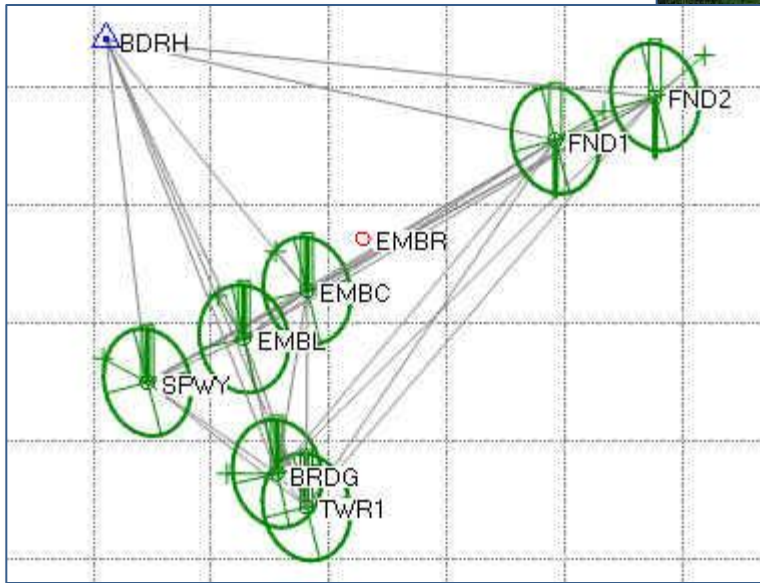
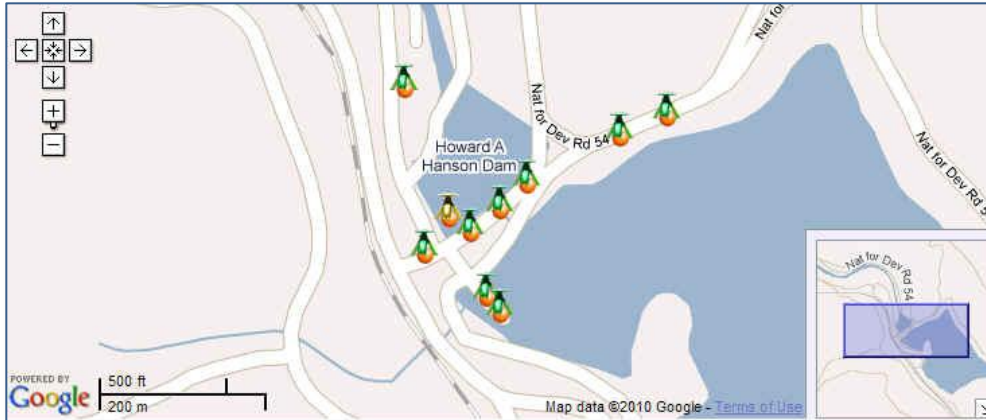
- Kalman filter:
 - Static
 - Convergence time: 24 h
 - Reaction time: days
 - Moderate Movement
 - Convergence time: 1-2 h
 - Reaction time: minutes
 - Sudden Movement
 - Convergence time: ~ 0
 - Reaction time: seconds
 - Custom
 - Depending on parameters

Analysis Tools



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Mapping Options



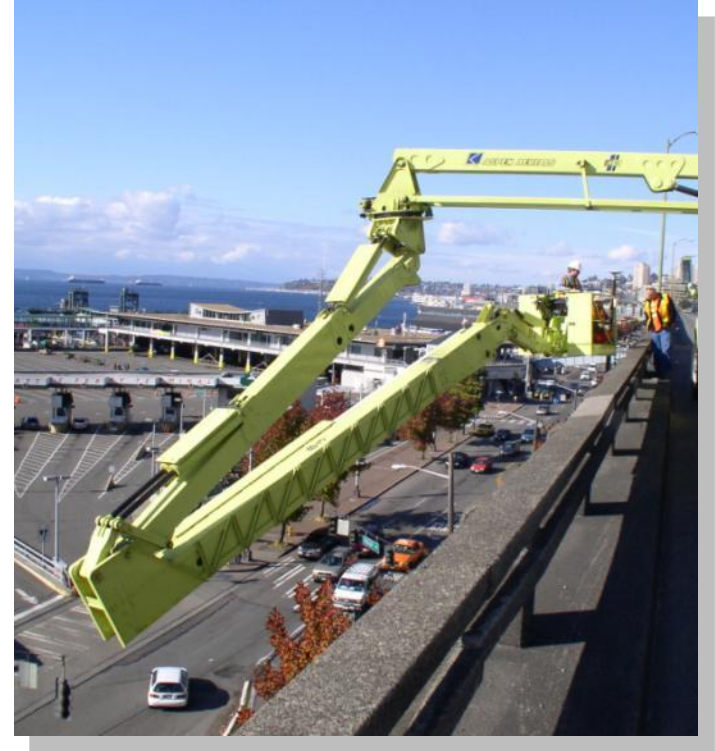
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Integrated Monitoring Study – Lesson Learned

- Confirmation of Tolt Findings
- Communications Options Explored
- When you have to save money, you will find ways to.
- Can build cheaper than thought, but not for as little as we spent
- Server simplicity/redundancy a plus
- Motion engine behaviors refined
- Integrated optical feasible and a huge plus

Full implementation suspended indefinitely due to budget constraints. Minimal monitoring (GNSS only) to continue.

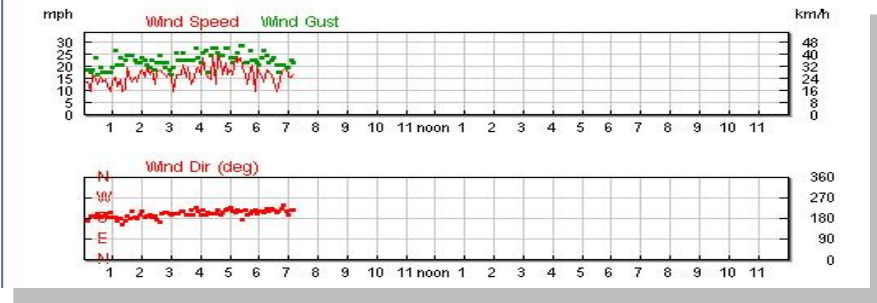
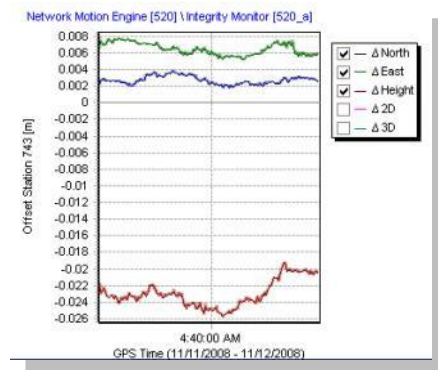
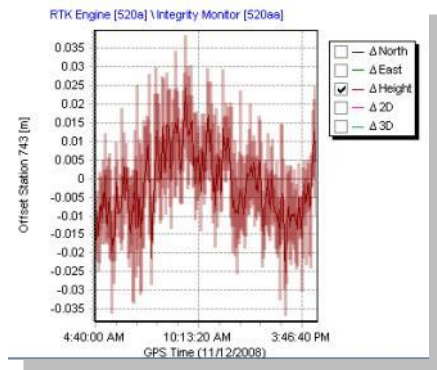
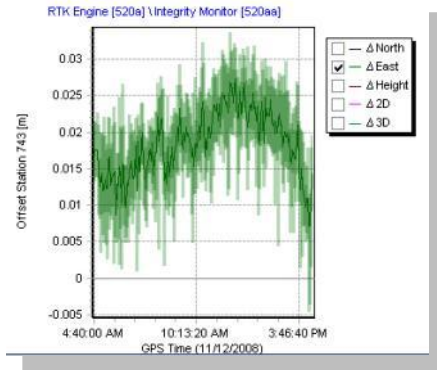
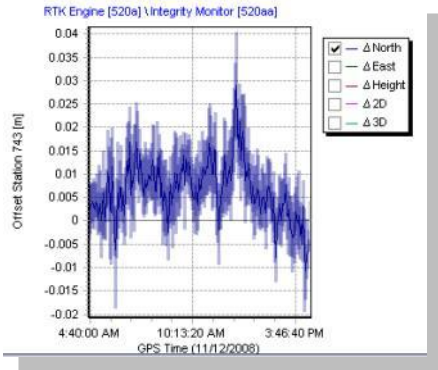
Elevated Highway



Floating Bridge and High-Rise



Floating Bridge



Wind Load on Floating Bridge





S. GROSS

"It sort of makes you stop and think, doesn't it?"