

WV VRS Integrity Manager Proposal

Coal Slurry Impoundment,
Bridge, and Dam Monitoring
Peter J Dailey, PhD

Agenda

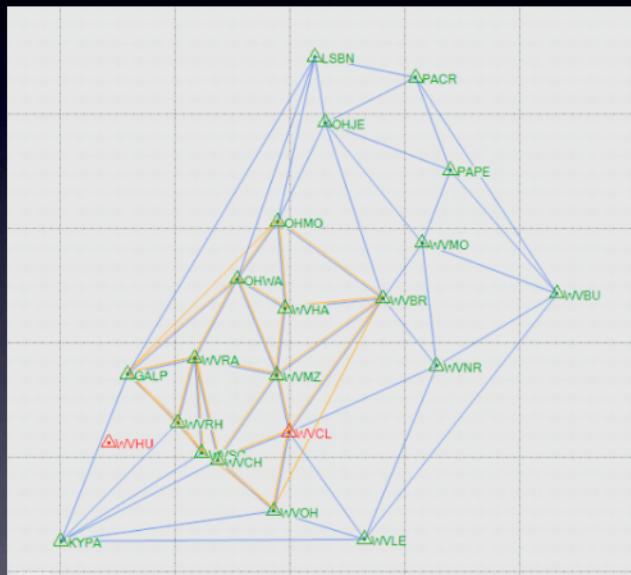
- Introduction
- System Overview
- Case studies & other applications
- Questions/Discussion

Terms

- GNSS: Global Navigation Satellite System
 - GPS, GLONASS, Galileo, Compass
- CORS: Continuously Operating Reference Station
- VRS: Virtual Reference Station server software
- WVCORS/VRS: WVDOH funded, RTI managed network of CORS and VRS software
- Kalman filter: a mathematical method using measurements observed over time with random variations to produce values that tend to be close to the true value of the measurement

WVCORS/VRS Status

- 26 June 2010
- Additional 25 CORS
- Permit GNSS RTK statewide
 - ± 1 cm horizontal
 - ± 2 cm vertical



WV VRS

Network Motion Engine

	Map 2D	Current Displacements	Adjustment	Displacement Chart	Axis Rotations	NMEA Output		
	Station Name	Station Code	Axis Rotation	Δ Northing [m]	Δ Easting [m]	Δ Height [m]	Δ 2D [m]	Δ 3D [m]
●	Harrisville, WV	WVHA	<input type="checkbox"/>	-0.010	0.172	-0.056	0.173	0.182
●	Elkins, WV	WVNR	<input type="checkbox"/>	0.003	0.137	0.068	0.137	0.153
●	Clay, WV	WVCL	<input type="checkbox"/>	0.009	-0.042	-0.143	0.043	0.149
●	Red House, WV	WVRH	<input type="checkbox"/>	0.005	0.067	-0.031	0.067	0.074
●	Lewisburg, WV	WVLE	<input type="checkbox"/>	0.014	-0.003	-0.058	0.014	0.060
●	Bridgeport, WV	WVBR	<input type="checkbox"/>	0.008	0.058	-0.006	0.058	0.059
●	Cranberry, PA	PACR	<input type="checkbox"/>	0.010	0.058	-0.002	0.059	0.059
●	Paintsville, KY	KYPA	<input type="checkbox"/>	0.017	0.048	-0.024	0.051	0.057
●	Perryopolis, PA	PAPE	<input type="checkbox"/>	0.006	0.053	-0.002	0.054	0.054
●	Charleston, WV	WVCH	<input type="checkbox"/>	0.008	0.049	-0.013	0.050	0.052
●	Mount Zion, WV	WWMZ	<input type="checkbox"/>	-0.013	0.041	0.027	0.043	0.051
●	Oak Hill, WV	WVOH	<input type="checkbox"/>	0.026	0.030	-0.017	0.040	0.043
●	South Charle... South Charle... South Charle...	WSC	<input type="checkbox"/>	0.005	0.023	-0.009	0.024	0.026
▲	Burlington, WV	WBU		0.000	0.000	0.000	0.000	0.000
▲	Wintersville, WV	OHJE		0.000	0.000	0.000	0.000	0.000
▲	Ravenswood, WV	WVRA		0.000	0.000	0.000	0.000	0.000
▲	Gallipolis, OH	GALP		0.000	0.000	0.000	0.000	0.000
▲	Marietta, OH	OHWA		0.000	0.000	0.000	0.000	0.000
▲	Lisbon, OH	LSBN		0.000	0.000	0.000	0.000	0.000
▲	Morgantown, WV	WVMO		0.000	0.000	0.000	0.000	0.000
▲	Woodsfield, OH	OHMO		0.000	0.000	0.000	0.000	0.000

VRS Integrity Manager

- Add-on package to the WVDOH Virtual Reference Station (VRS) server software
- Detects changes in GNSS/GPS antenna positions versus reference coordinates over time
- Measures these changes and keeps records to allow trend analysis
- Automated alarms and reports based on user defined thresholds



Types of network dynamics

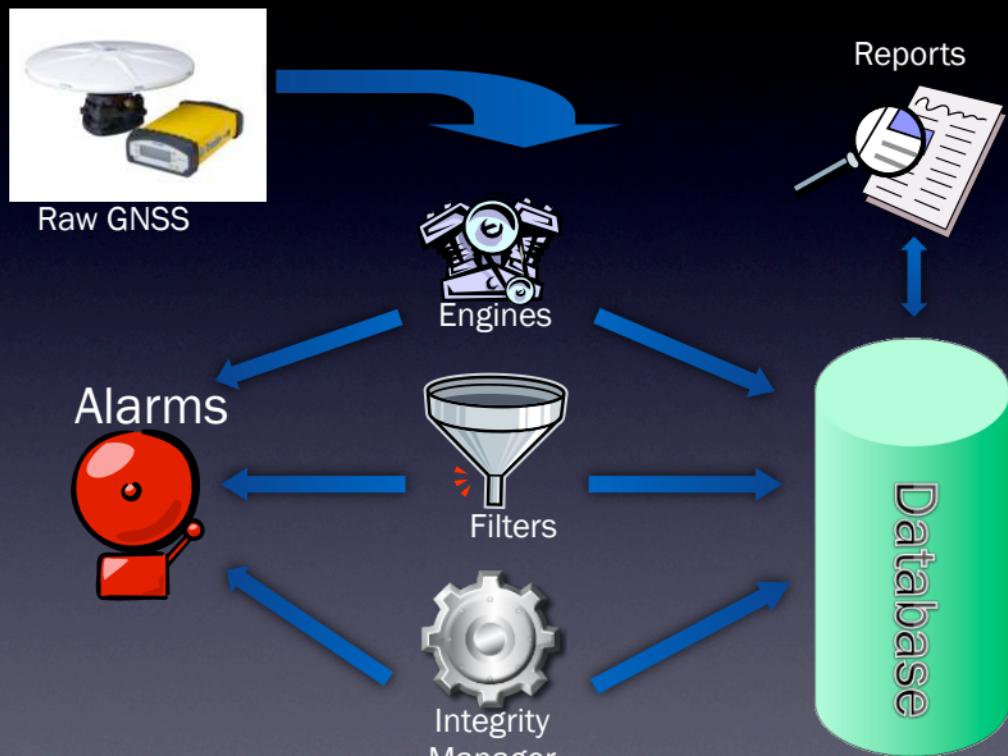
- Acute, Localized
 - Affects a small portion of the network
 - e.g., Roofing; vehicle collision with pillar
- Acute, Widespread
 - Affects the overall network
 - e.g., earthquake
- Chronic
 - Affects smaller & larger portions of the network
 - e.g., Subsidence, tidal loading, continental drift



What does an Integrity Monitor offer?

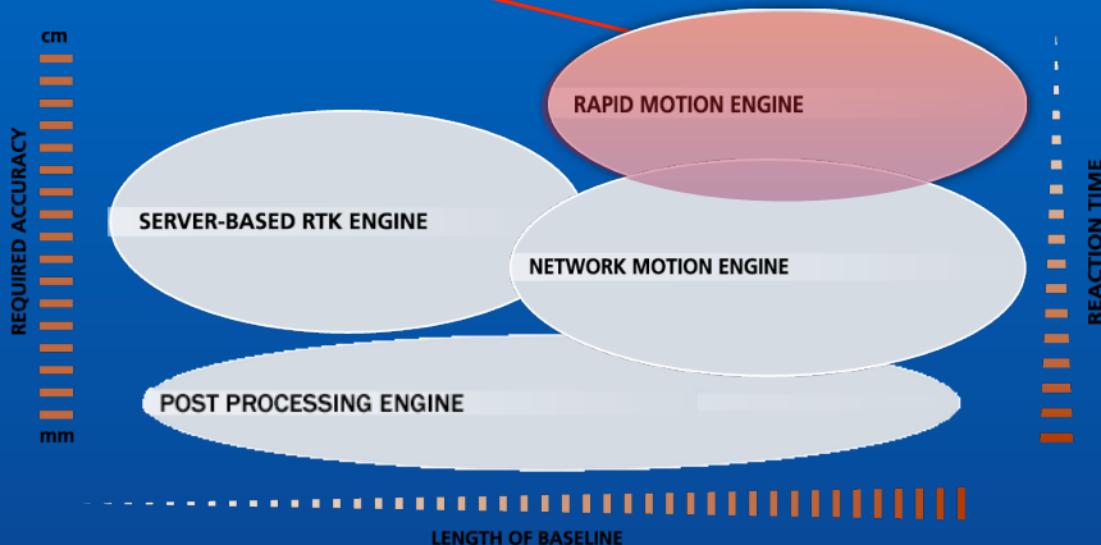
- The use of GNSS for monitoring a site of interest
 - i.e., dam, mine wall, CORS, coal slurry impoundment
- Ensures quality geodesy
 - Tie the WVCORS network to the national/regional network
- Discover & compensate for trends in station motion
- Reporting to provide indications of station stability or movement

Software Conceptual Model

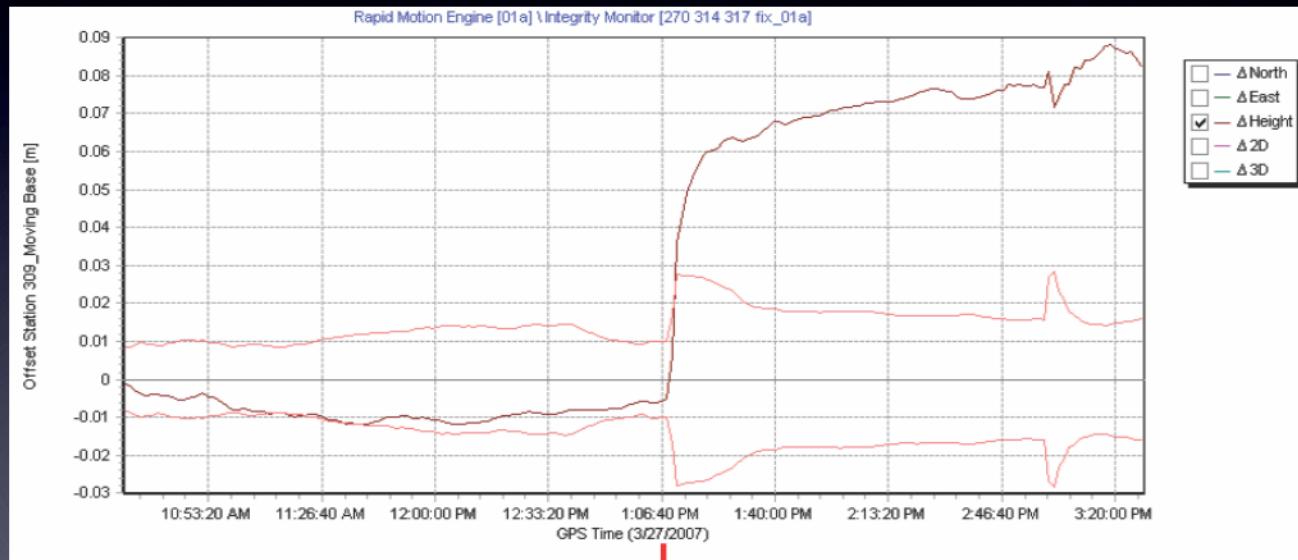


Comparing the Engines

Detect 3cm/sec over large distances



System reaction time



CSDS Installation

California Survey & Drafting Supply

Uses Integrity Manager software to:

- Monitor the integrity of the reference stations in the CSVSN network
- Expand the CSVSN network when stations are added
- Calculate new coordinates when updates are required



*California Survey Virtual Survey Network
www.csdsinc.com

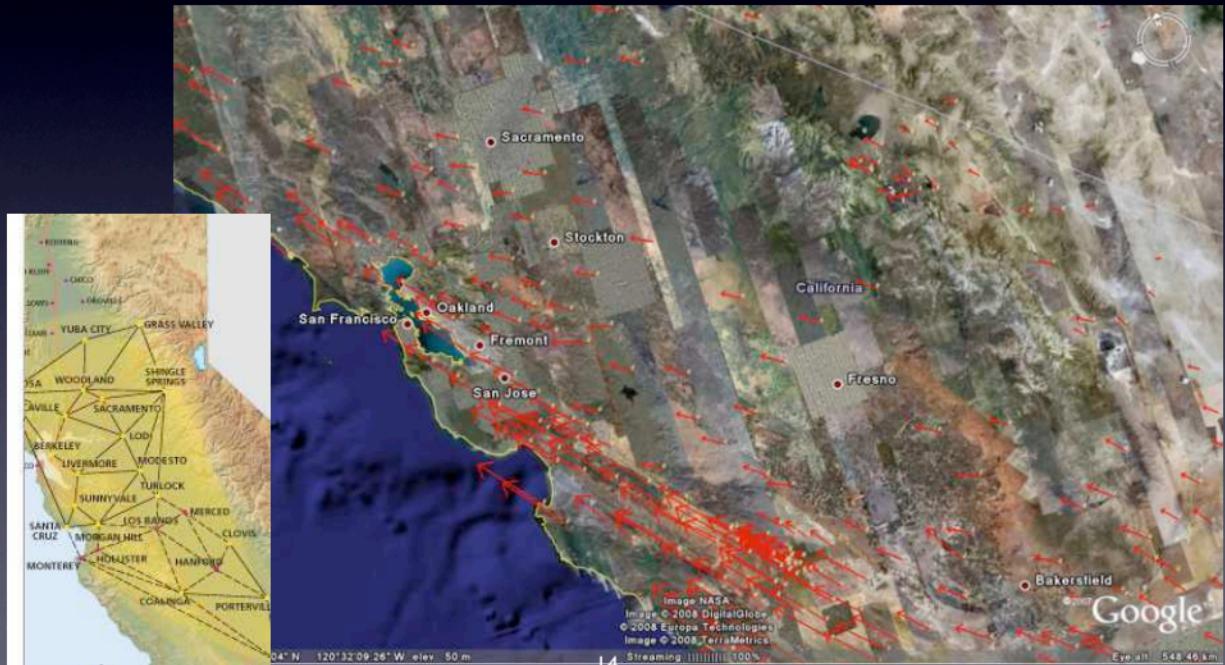
CSDS IM Installation

California fault movement caused the displacement in the concrete wall



CSDS IM Installation

Monitored Fault Velocities





File



Tree



CSDS Integrity Manager

Map 2D

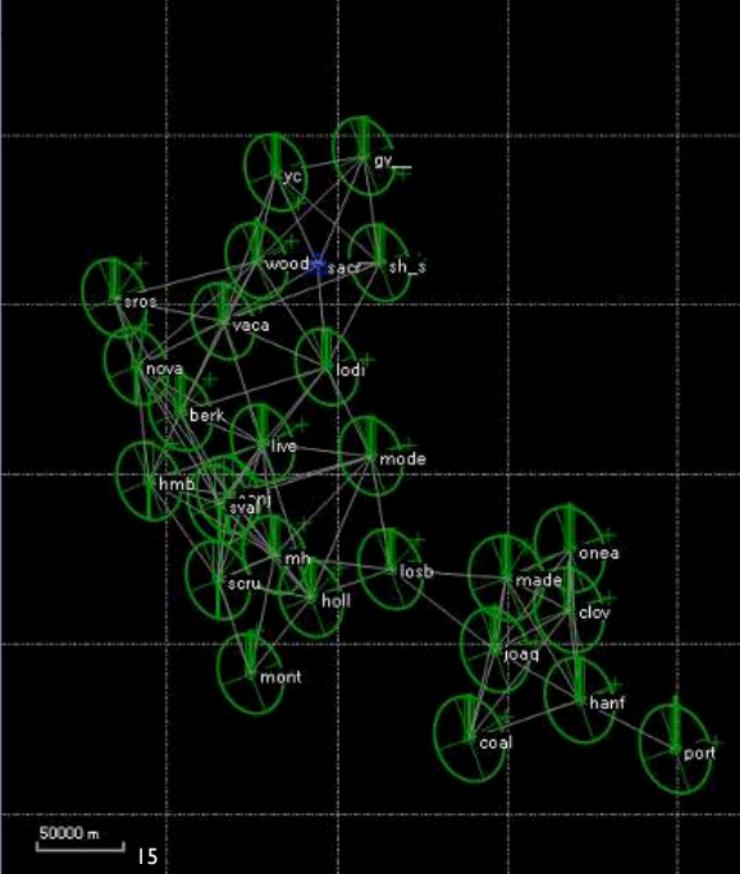
Current Differences

Adjustment

Offset Chart

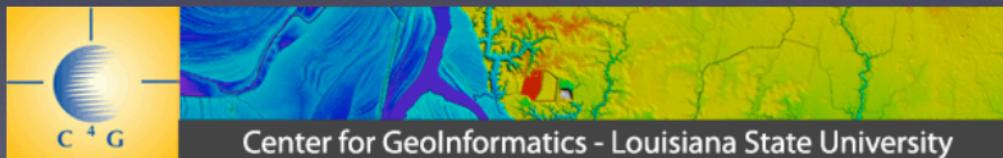
NMEA Output

- Trimble Integrity Manager [CSDS_Jan17_07]
 - Alarm Manager [CSDS]
 - Device Manager [Default]
 - Ephemeris Download [Default]
 - Ephemeris Manager [Default]
 - Post Processing Engine [CSDS]
 - Post Processing Engine [CSDS_Bay_Area]
 - Post Processing Engine [CSDS_Central_Valley]
 - Synchronizer [CSDS]
 - Network Motion Engine [CSDS]
 - Rapid Motion Engine [CSDS]
 - Integrity Monitor [CSDS_RapidMotion]
 - RTK Engine [CSDS]



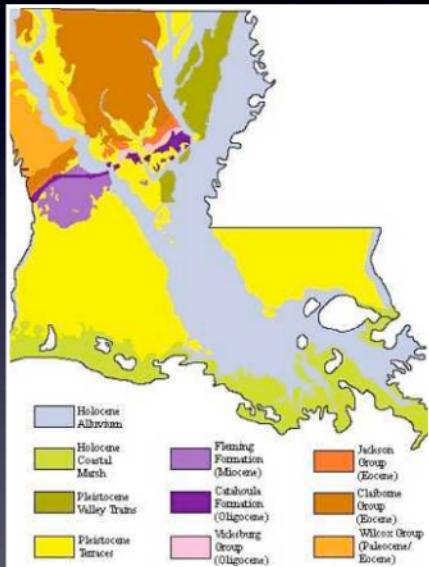
Installation example - Louisiana State University (C4G - LSU)

- Providing critical post-Katrina survey data across LA through GULFNet
 - www.c4g.lsu.edu
- Integrity Manager monitors station integrity
- Provides data for a geologically dynamic part of USA



LSU

- Entire state built from Mississippi River mud
- Natural subsidence caused by sediment/water loading, faulting, compaction.
- Flood control measures (river levees, dams) are starving yellow/green areas of fresh sediment, consequently coastal LA is now only sinking.
- Mississippi River areas may be loaded by tidal effects



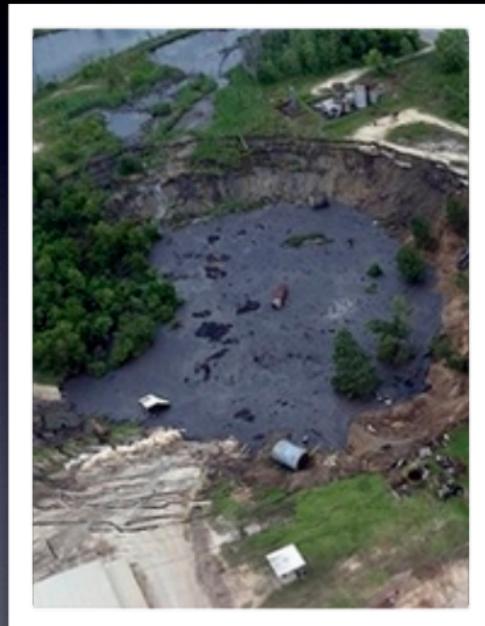
LSU GULFNet

GULFNet / Integrity
Manager stations



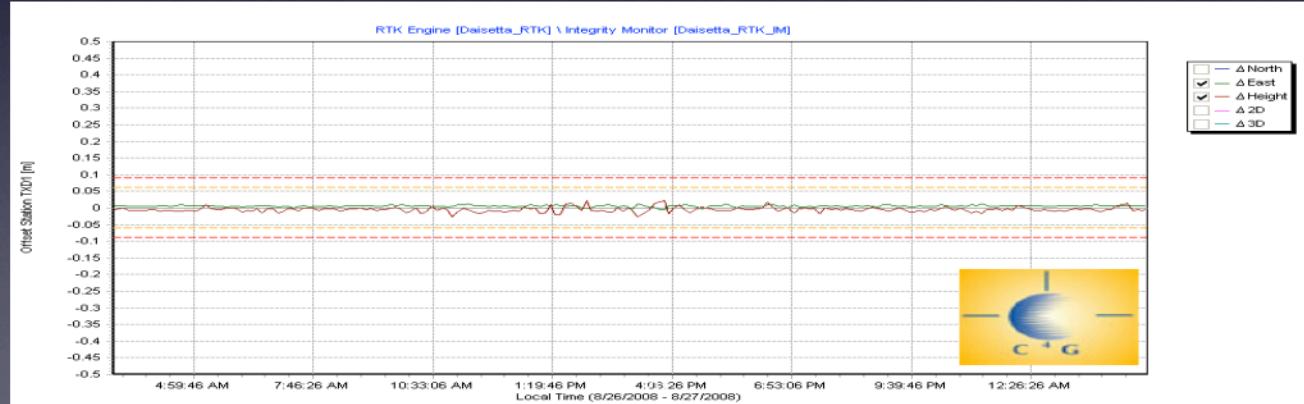
Daisetta TX sinkhole

- Special TIM project
 - Salt dome – waste water pumping causes collapse

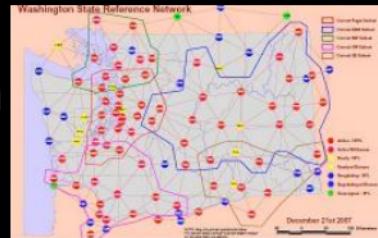


Daisetta Sinkhole Monitor

- LSU provides near real-time graphs (5 sec delay) of station integrity
- <http://www.c4g.lsu.edu/> Click on “Daisetta Sinkhole” for most recent chart



Structure Monitoring Installation Seattle Public Utilities (SPU)

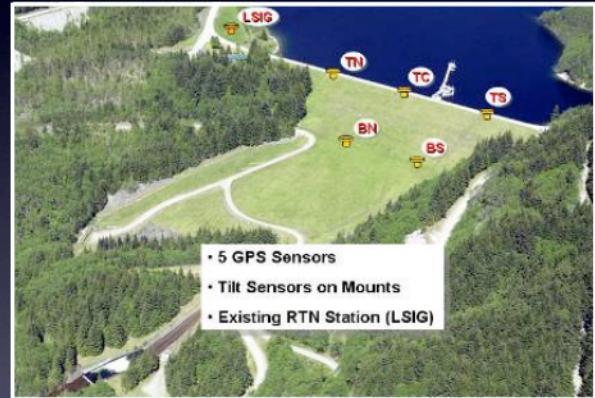


- Washington State Reference Network
 - www.wsrn.org
 - Cooperative statewide real-time Trimble RTKNet VRS and post processing service network
- Integrity Manager software
 - Providing coordinates and integrity management for stations in the WSRN
 - Positioning and status of several antennas located on earthen dam

SPU Tolt dam



- Earthen construction
- Specific engineering requires GNSS tracking of dam status
- Reference stations outside dam operate as site control (LSIG is part of the VRS network)





WSRN
CORS
“LSIG”

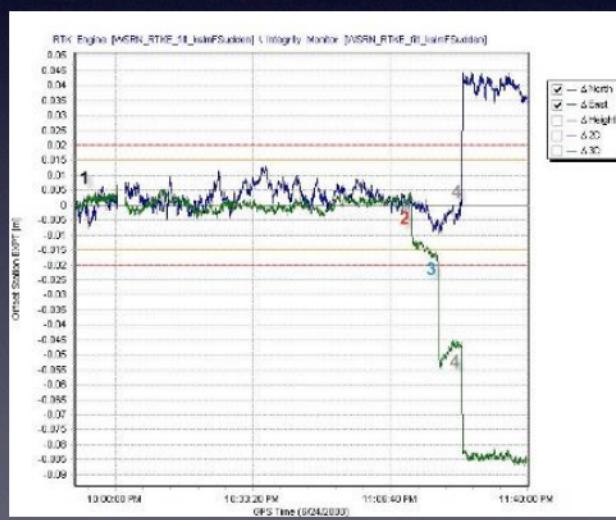




SPU dam

Simulated movement event

Precision results exceed client need



The screenshot shows the Trimble Integrity Manager interface. The top menu bar includes 'File', 'View', 'Edit', 'Help', and several icons. Below the menu is a toolbar with buttons for 'New', 'Open', 'Save', 'Print', 'Zoom In', 'Zoom Out', and 'Exit'. The main window has tabs for 'Map View', 'Current Differences', 'Adjustments', 'Filter Chart', and 'Mobile Output'. The 'Map View' tab is active, displaying a coordinate system with axes labeled 'X', 'Y', and 'Z'. A point labeled 'L633' is plotted. The 'Current Differences' tab shows a list of GNSS receiver locations and their status:

- GNSS Receiver [B-A] (Storage [MSRH_1sec_T01])
- GNSS Receiver [B-B] (Storage [MSRH_1sec_T01])
- GNSS Receiver [B-C] (Storage [MSRH_1sec_T01])
- GNSS Receiver [B-D] (Storage [MSRH_1sec_T01])
- GNSS Receiver [B-E] (Storage [MSRH_1sec_T01])
- GNSS Receiver [B-F] (Storage [MSRH_1sec_T01])
- GNSS Receiver [B-G] (Storage [MSRH_1sec_T01])
- GNSS Receiver [B-H] (Storage [MSRH_1sec_T01])
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- GNSS Receiver [B-L] (Storage [MSRH_1sec_T01])
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- GNSS Receiver [C-C] (Storage [MSRH_1sec_T01])
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- GNSS Receiver [L-L] (Storage [MSRH_1sec_T01])

The bottom left corner shows a 'Saved configuration: 2008_06_24wSHN'. The bottom right corner shows the 'Trimble Integrity Ma...' logo.

Tolt Dam High Flow Event

- Jan 7th-10th 2009 weather in WA recorded the Tolt outflow at very high levels
- Downstream
 - River bank overflow onto highways



Tolt Dam High Flow Event





Tolt Dam High Flow Event

- ~ 2000 cfs drop in flow detected at USGS sensors 12-148000 & 12-148300

Sensor 1214800 4:00 am 3640cfs HIGH FLOW

4:15 am 963 cfs **SUDDEN DROP**

4:30 am 3820 cfs HIGH FLOW

01/08/2009 03:58	6.27	3,500
01/08/2009 03:45	6.30	3,620
01/08/2009 04:00	6.31	3,640
01/08/2009 04:15	4.34	963
01/08/2009 04:30	6.40	3,820
01/08/2009 04:45	6.41	3,840

Sensor 12148300 4:30 am 2570 cfs HIGH FLOW

am 467 cfs **SUDDEN DROP**

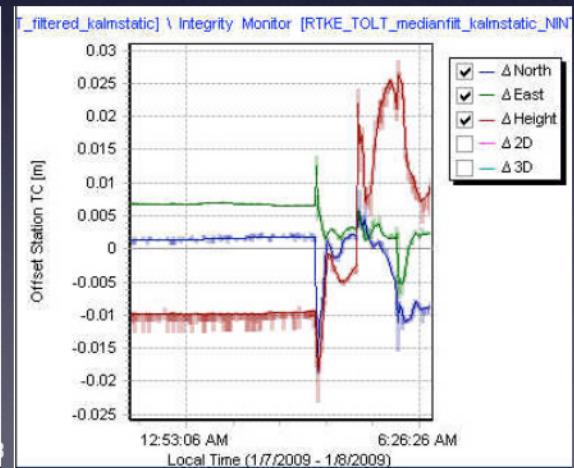
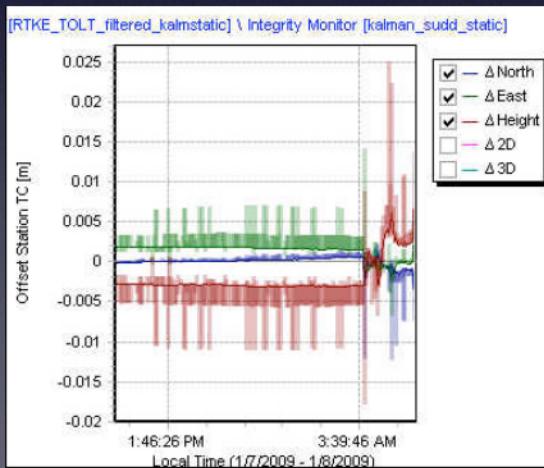
am 2430 cfs HIGH FLOW



Tolt Dam

High Flow Event

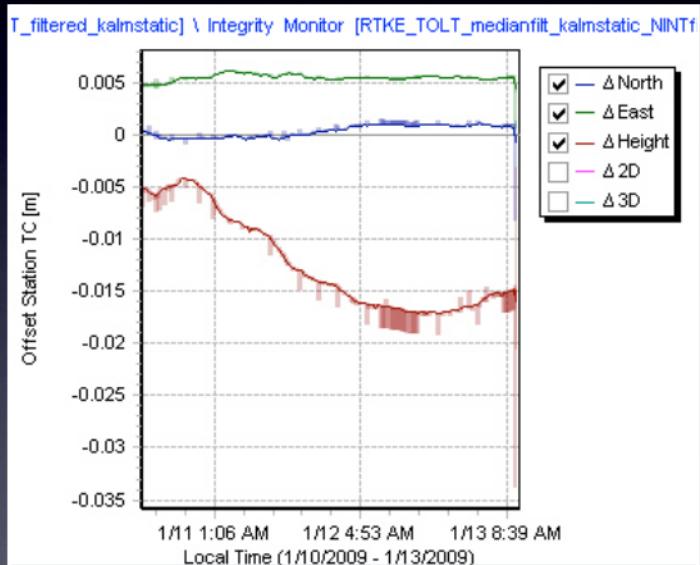
- TIM registers sudden change
- Undulations when >1000 cfs flow
- Dam crest rises as expected



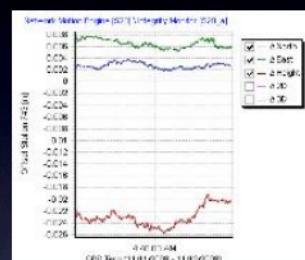
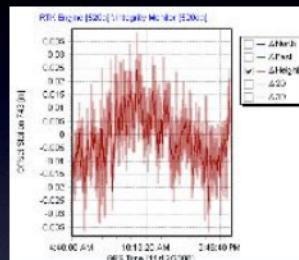
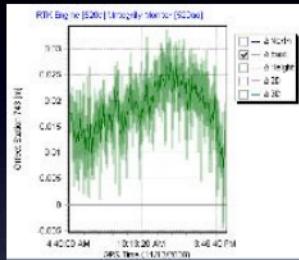
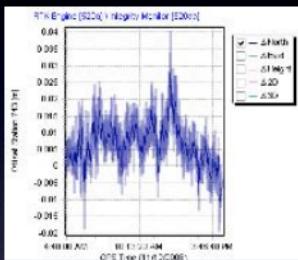
Tolt Dam

High Flow Event

- Excess water in reservoir released by 11 Jan 09
- Dam returns to original position



SPU IM



- In a high wind/wave environment, the structure pitches/twists in response about 10cm
- Deck pitches as expected



SPU IM

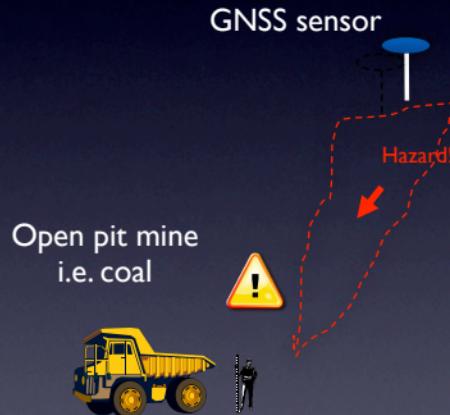
Bridge Monitoring

- Monitoring an aging elevated expressway
- Providing engineers with structural performance information



Mining Applications

- GNSS monitoring is suited to open-pit mining and where sub-surface deformation could occur
- Manual observation of control marks via RTK/PPS can be supplemented and reduced by installing 24/7/365 monitored GNSS sensors. Streamline field operations.





South African Mine

Image © 2009 DigitalGlobe

3°59'24.43" S 31°07'47.30" E elev 3 m

33

Streaming 100%

Eye alt

South African Mine in 3D



Diamond Mine

Jwaneng, Botswana

- Deformation Monitoring or slope stability monitoring (SSM) is almost always done for safety reasons
- Makes good economic sense, for example:
Jwaneng Diamond Mine:
 - Design slopes at 5-10% probability of failure
 - 15-degree increase in one slope angle saves 39 Mt
 - Savings of 39 MT of waste @ \$1.5 / ton
- Government Mining Regulator (DME) agreed to steeper slopes providing SSM in place



Image © 2009 DigitalGlobe
© 2009 Cnes/Spot Image

©2007 Google

Pointer 24°31'29.76"S 24°42'18.39"E elev 1109 m

Streaming 37 100%

Eye alt 5.67 km

Berg River Dam South Africa



Berg River Dam

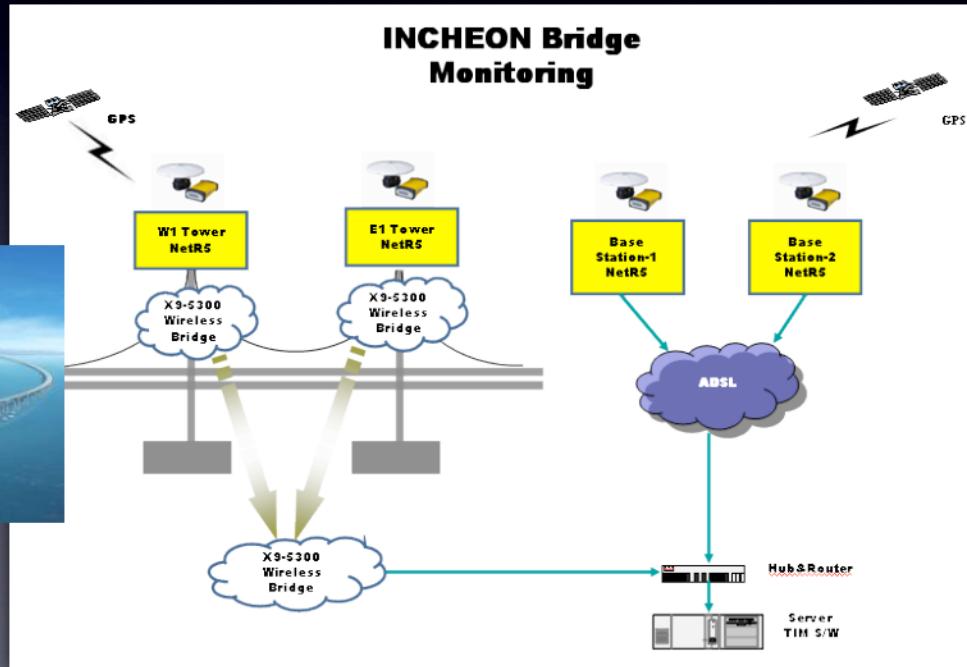


Sensor and Data
Communication



Structure Monitoring

- South Korean Incheon Bridge Towers IM plan



Structure Monitoring

- Taiwan legislation requires monitoring of 200+ bridges after >10 fatalities



Coal Slurry Impoundment Construction

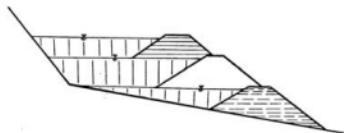


Figure 1: Upstream construction method

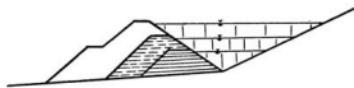


Figure 2: Downstream construction method

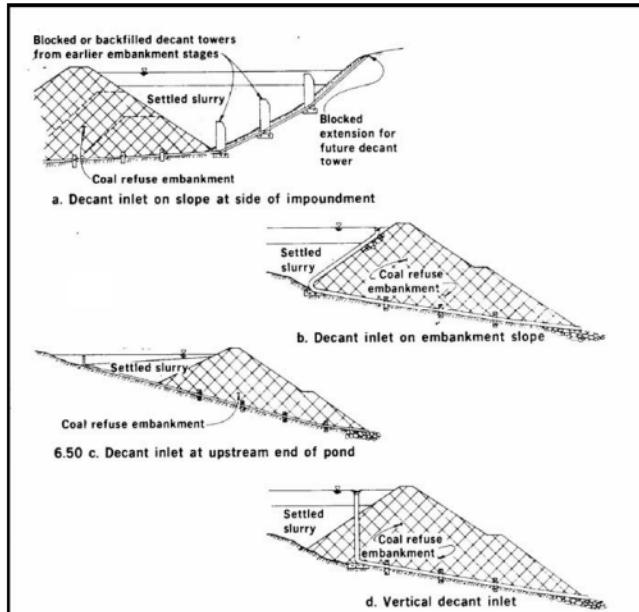


Figure 3: Decanting Systems

Failure Modes

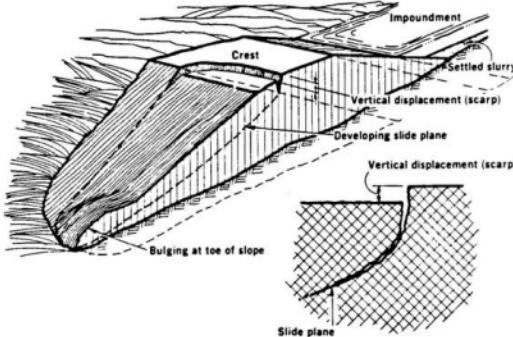


Figure 4: Surface sloughing of material on embankment.

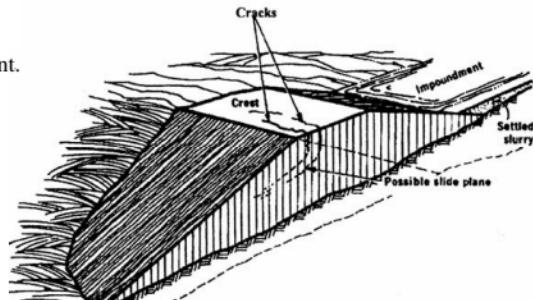
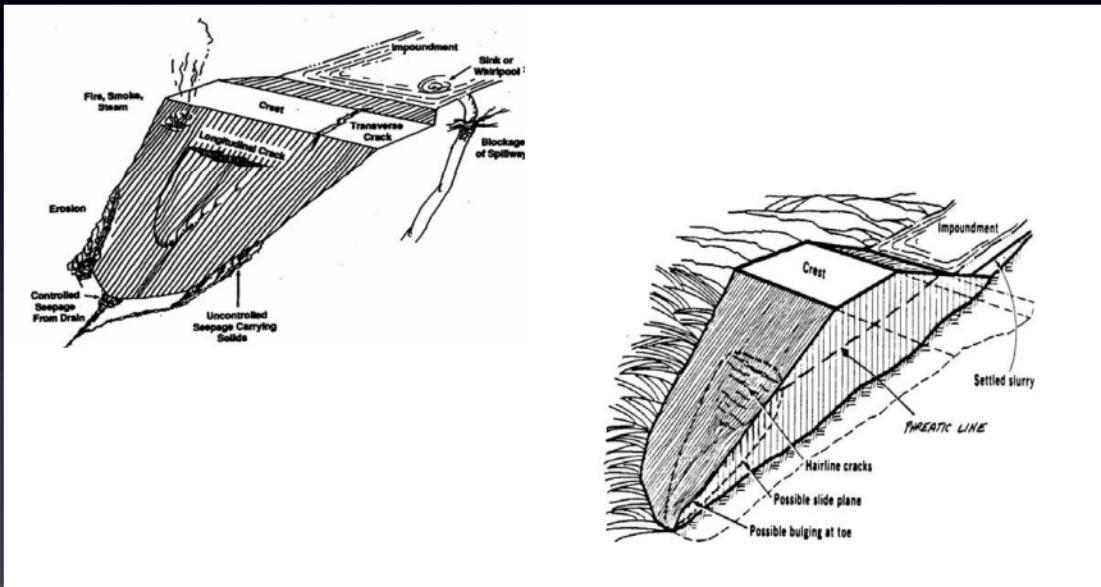


Figure 5: Cracks on Embankment Crest

Indicators



Site Instrumentation

Data Stream Options

- Slope movement
 - Displacement - GNSS sensor
 - Tilt - 2 axis sensor
- Meteorological Information
 - Rain gauge
 - Temperature
 - Pressure
- Other
 - Decant level

WV IM Hardware/ Software Requirements

✓ Statewide CORS Network

\$600,000

✓ Data Center, servers, VRS software

\$150,000 + \$≈50,000/yr maintenance

✗ Rapid Motion Integrity Monitor add-on to VRS software

\$20,000

✗ Site GNSS sensors, data communication to Data Center

\$15,000-20,000 each + installation + maintenance

2 GPS receivers & antennas available for research (\$16,000)