“River Scour Monitoring System for Pipeline Threat Prevention”

Research Contractor: Arizona State University

Subcontractor: Xylem/Pure Technologies HM

Principle Investigator: Dr. Samuel T. Ariaratnam

Contract Number: 693JK31810011

Sponsors and Project Team

PROJECT TEAM:

- Dr. Samuel Ariaratnam, Arizona State University (PI)
- Tyler Lich, Xylem/Pure Technologies HM
- Rob Zmud, Xylem/Pure Technologies HM
- Shamus McDonnell, Xylem/Pure Technologies HM

SPONSORS:

- Peter Song, Enbridge Pipelines
- Doug Dewar, Pembina Pipelines

River Scouring Monitoring System is a novel active monitoring application for ***"threat prevention for pipeline river crossings".*** End-user adoption should ensue due to damage prevention efforts.

On September 21, 2016, ExxonMobil Corp. agreed to pay $12 million to the State of Montana and the U.S. government as a result of a pipeline rupture on July 1, 2011 that spilled oil into the Yellowstone River causing damage to natural resources. Over 63,000 gallons of crude oil was released affecting 85 miles of the flood-swollen Yellowstone River. Exxon estimated that they spent close to $135 million in cleanup and compensation to affected property owners (Reuters, Sept 21, 2016).

In January 2015, the Poplar oil pipeline spilled 40,000 gallons of oil into the Yellowstone River contaminating local water supplies and harming local wildlife. The pipeline operator, Bridger Pipeline, claimed that a 2012 inspection revealed that the pipeline was buried at a depth of 8 feet (2.4 meters) under the river bed, which is 4 feet (1.2 meters) deeper than the minimum depth as per 49 CFR Part 195.248, Subpart D – Construction. Investigators found 120 feet (36 meters) of exposed pipeline following the spill. Depletion of cover resulting from flooding events was deemed to be responsible for the damage.

Failure of Hazardous Liquid Pipelines from Depletion of Cover at Inland Bodies of Water – 1993 to 2011 (adapted from PHMSA, 2013)

Operator	Product	Date of Occurrence
Amoco Pipeline Co.	Refined Petroleum	April 1, 1993
Williams Pipeline Co.	Highly Volatile Liquid	July 3, 1993
Exxon Pipeline Co.	Highly Volatile Liquid	October 19, 1994
Colonial Pipeline Co.	Refined Petroleum	October 20, 1994
Colonial Pipeline Co.	Refined Petroleum	October 20, 1994
Texaco Pipeline Inc.	Crude Oil	October 21, 1994
Texas Eastern Product Pipeline	Refined Petroleum	December 20, 1994
Chevron USA	Crude Oil	March 11, 1995
Conoco Inc.	Highly Volatile Liquid	October 7, 1998
Mid Valley Pipeline Co.	Crude Oil	January 26, 2005
Shell Pipeline Co. LP	Crude Oil	September 2, 2005
ExxonMobil Pipeline Co.	Refined Petroleum	June 14, 2007
Chevron Pipeline Co.	Crude Oil	December 23, 2009
ExxonMobil Pipeline Co.	Crude Oil	July 1, 2011
Nustar Pipeline Operating	Highly Volatile Liquid	July 15, 2011
Enterprise Products Operation	Refined Petroleum	August 13, 2011

Project Background/Problem Addressed

Hazardous liquid pipelines are mandated to maintain a minimum cover depth below the river bottom at crossings of inland bodies of water with widths greater than 100 feet (30 meters) from high water mark to high water mark as per *49 CFR Part 195.248, Subpart D – Construction*. These prescribed burial depths apply during the initial pipeline construction phase and not during system operation. Over time, river scour results in a reduction in the prescribed depth of cover that can compromise the pipelines. The problem addressed in this research was the development of a "River Scour Monitoring System" that serves as an "active" monitoring system capable of determining the degree of scour in a riverbed thereby alerting pipeline operators should the amount of cover of the pipeline become reduced. The technology is based on a temperature gradient decay method for monitoring a subject pipeline river crossing for scour conditions. Field demonstrations at crossing sites provided a validation of the applicability for detecting depletion of cover above an installed pipeline. The Arizona State University-PureHM Inc. team brings complementary expertise to the project.

49 CFR Part 195.248, Subpart D – Construction: Liquid pipelines are mandated to maintain a minimum cover depth of 48 inches (1219 mm) below the river bottom at crossings of inland bodies of water with widths greater than 100 feet (30 meters) from high water mark to high water mark.

- The exception is when solid rock requiring blasting is encountered where the minimum burial depth is relaxed to 18 inches (457 mm).

49 CFR 195.412, Subpart F – Operation and Maintenance: Inspection intervals of rights-of-way and crossings under navigable waters are mandated to pipeline operators.

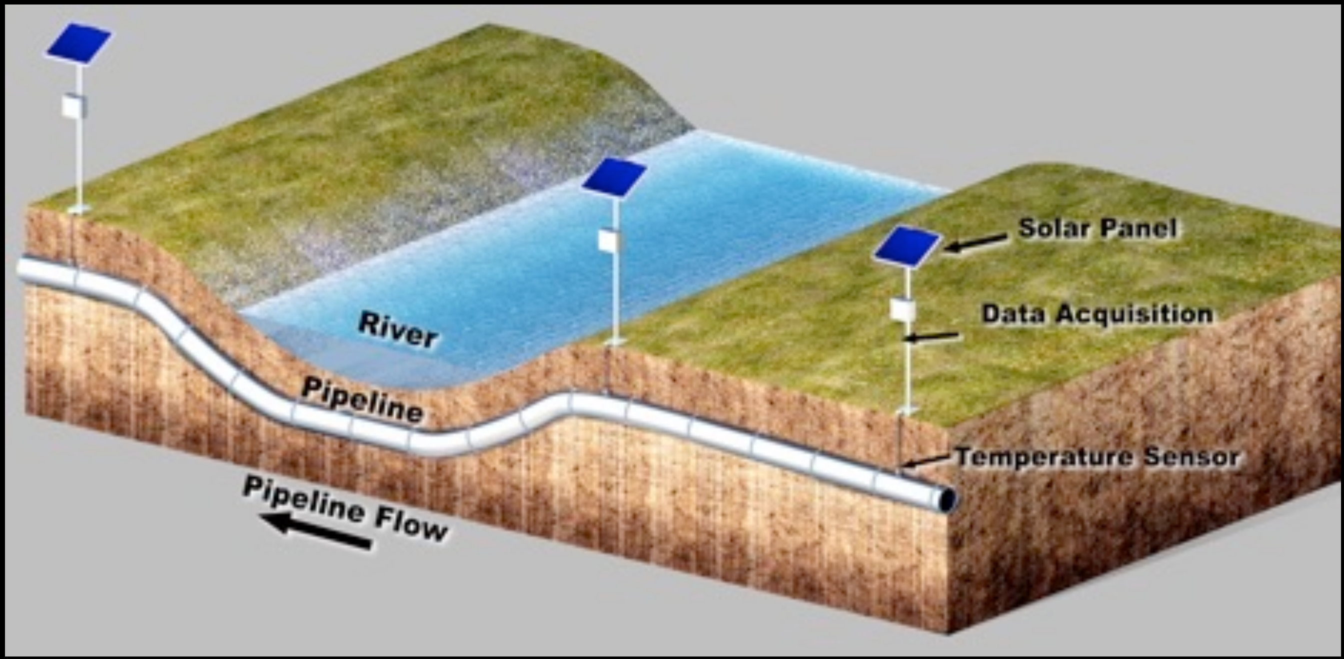
- Each operator is required to inspect the surface condition on or adjacent to each pipeline right-of-way at least 26 times in a calendar year not exceeding 3-week intervals.

End-users involved in the project were Enbridge Pipelines and Pembina Pipelines

Project Main Objective

Project Main Objective: The *development of a “River Scour Monitoring System” to benefit society by serving as an “active” monitoring system capable of determining the degree of scour in a riverbed thereby alerting pipeline operators should the amount of cover of the pipeline become reduced.*

- 49 CFR 195.452, which addresses pipeline integrity management in “high consequence” areas such as river crossings



Project Tasks and Funding

TASKS:

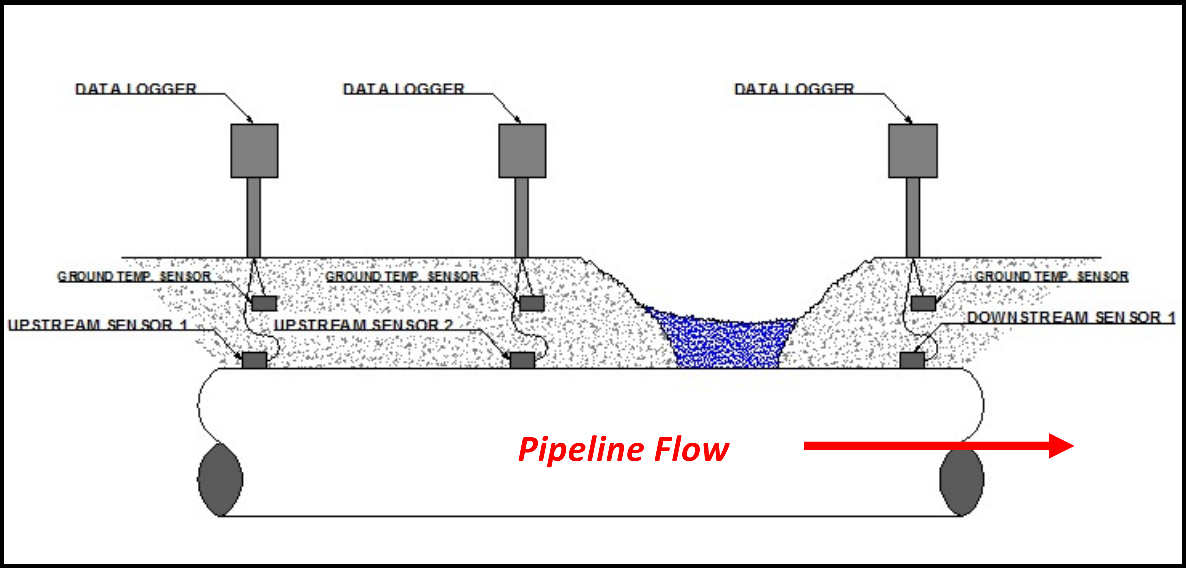
- Manufacture and deploy five demonstration River Scour Monitoring Systems (RSS) in North Dakota, Kansas and Alberta
- Collection of field data and monthly analysis of results
- Software/Website Upgrade
- Hardware System Upgrade
- Studied and analyzed the impact of Vortex-Induced Vibrations (VIV) on exposed pipelines computationally

FUNDING:

- Project Cost = $800,000 (08/18 – 08/21)

The RSS and How it Works

The image below illustrates how the RSS is intended to work. Two temperature sensors on upstream side of river measure "normal" heat loss or gain from earth, and are used to extrapolate expected temperature at third sensor on downstream side of river. The actual temperature is then measured at position three and compare to the predicted temperature to see if the pipe is gaining or loosing more heat than expected due to scour and pipe exposure to the flowing water.



Demonstration Project Pipelines River Crossing Sites

- ***Installation #1:*** Tongue River (North Dakota)
  - November 18-20, 2019
- ***Installation #2:*** Tongue River (North Dakota)
  - November 18-20, 2019
- ***Installation #3:*** Elk River (Kansas)
  - December 3-7, 2019
- ***Installation #4:*** Elk River (Kansas)
  - December 3-7, 2019
- ***Installation #5:*** Freeman River (Alberta)
  - March 7 – 11, 2020

*Each installation takes 3 days

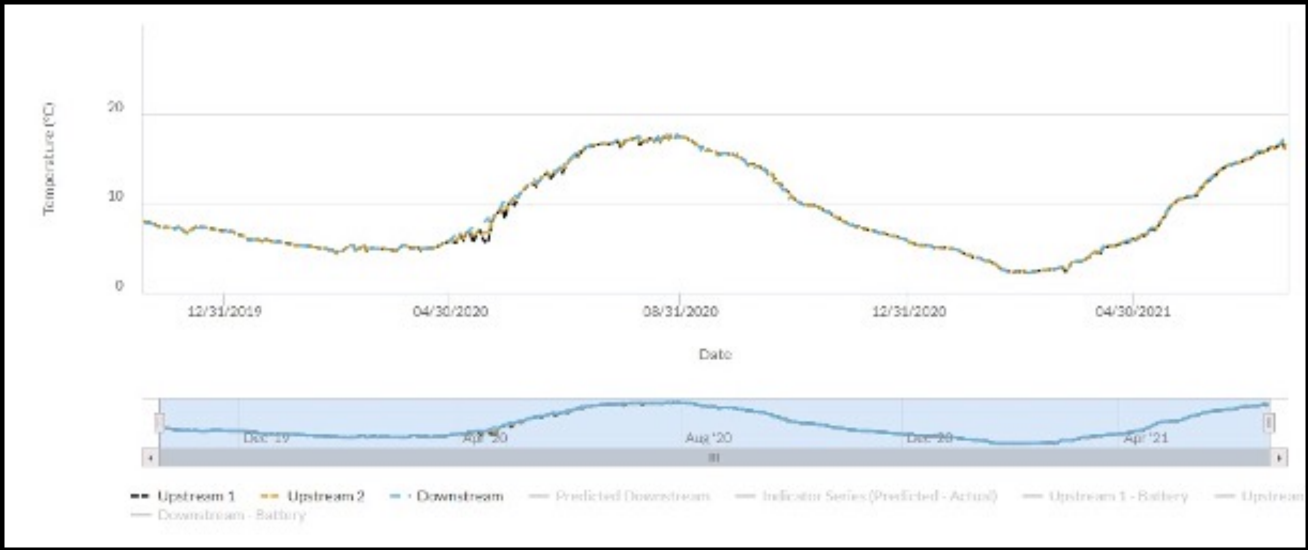
Tongue River, North Dakota

Elk River, S.E. Kansas

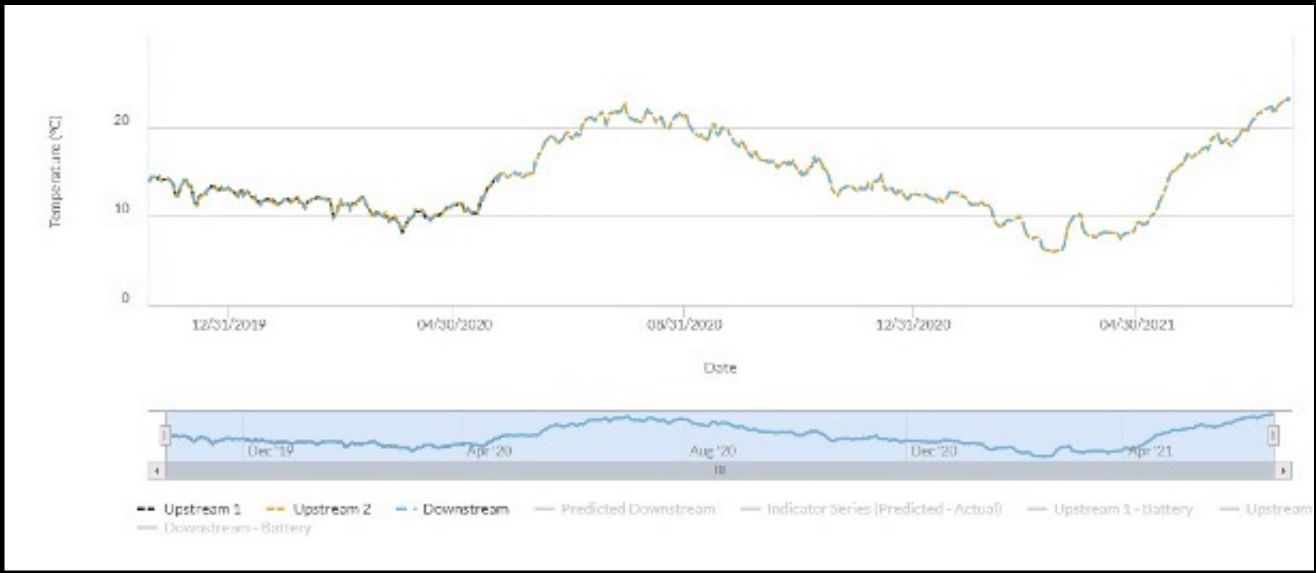
Pipeline 1 (built 1950s; open cut)– red line
Pipeline 2(built 2000s; HDD) – light blue line
Width of river = 150 ft.

Freeman River, Alberta

Data Collection Results

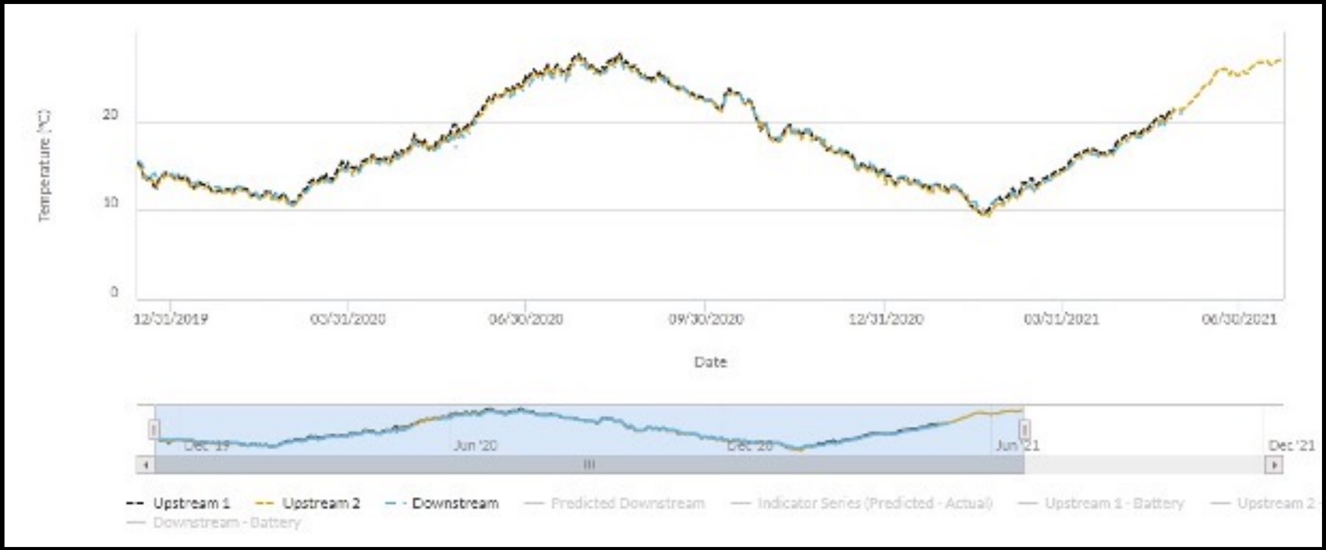


Pipeline Temperatures on Tongue River Pipeline #1

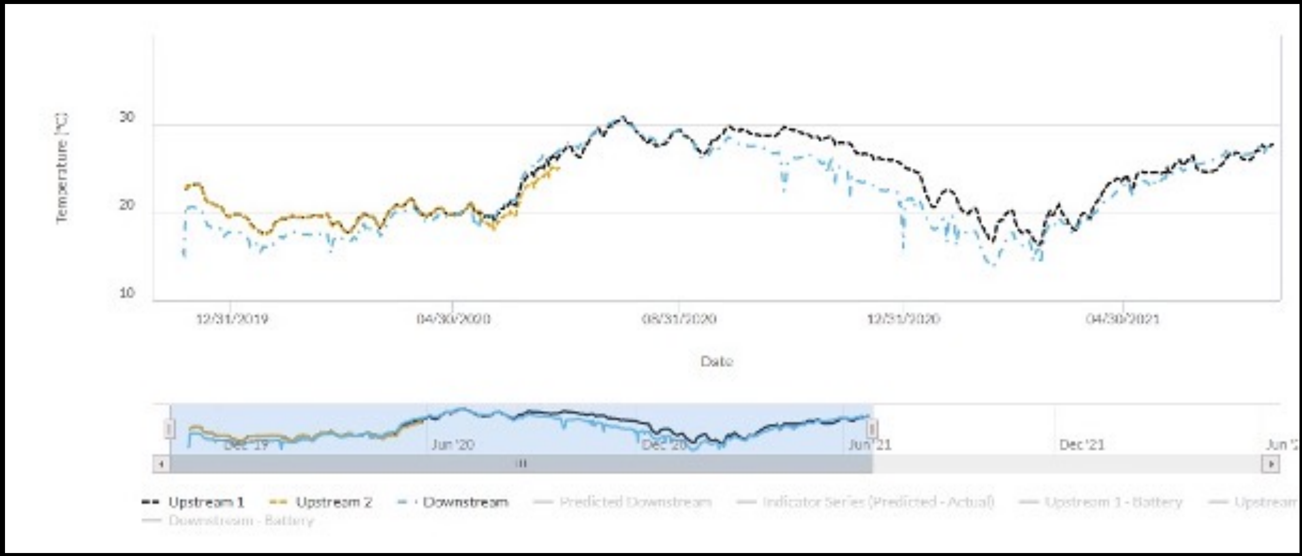


Pipeline Temperatures on Tongue River Pipeline #2

Data Collection Results

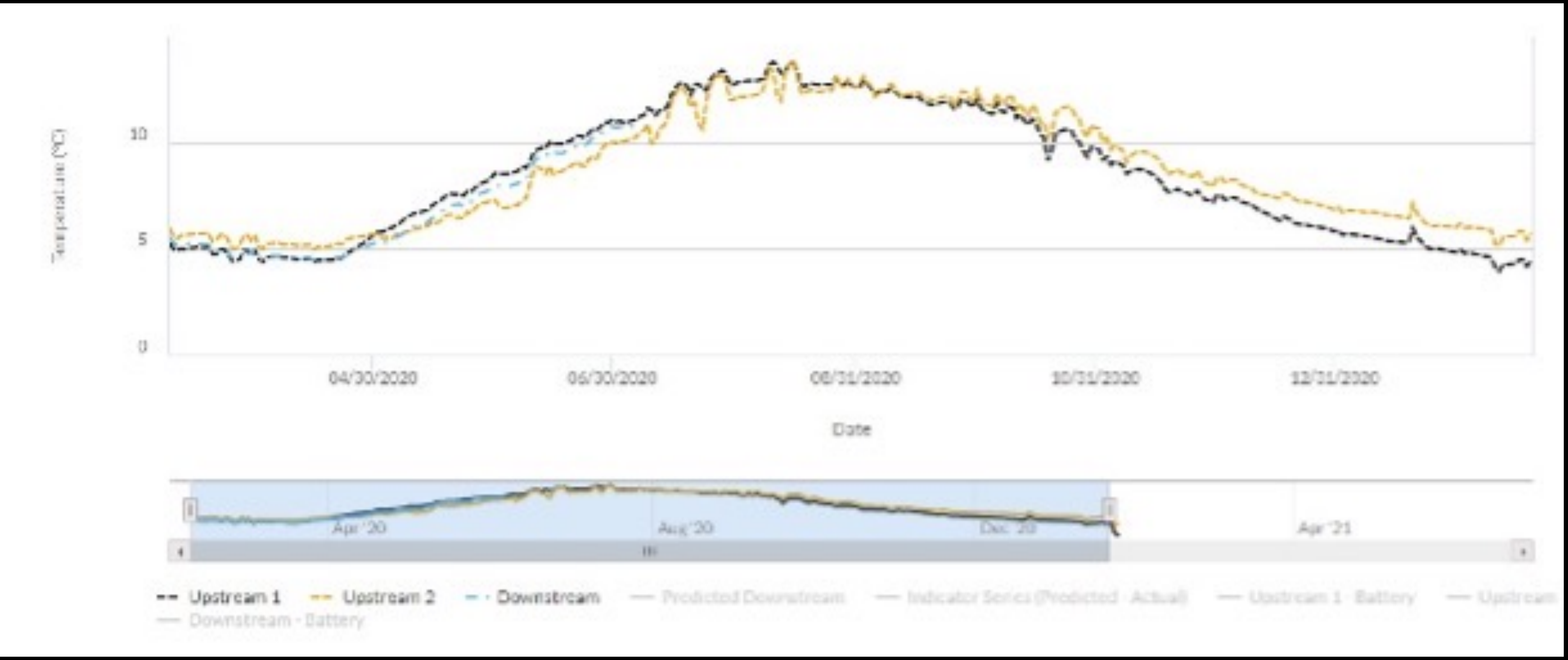


Pipeline Temperatures on Elk River Pipeline #1



Pipeline Temperatures on Elk River Pipeline #2

Data Collection Results



Pipeline Temperatures on Freeman River Pipeline

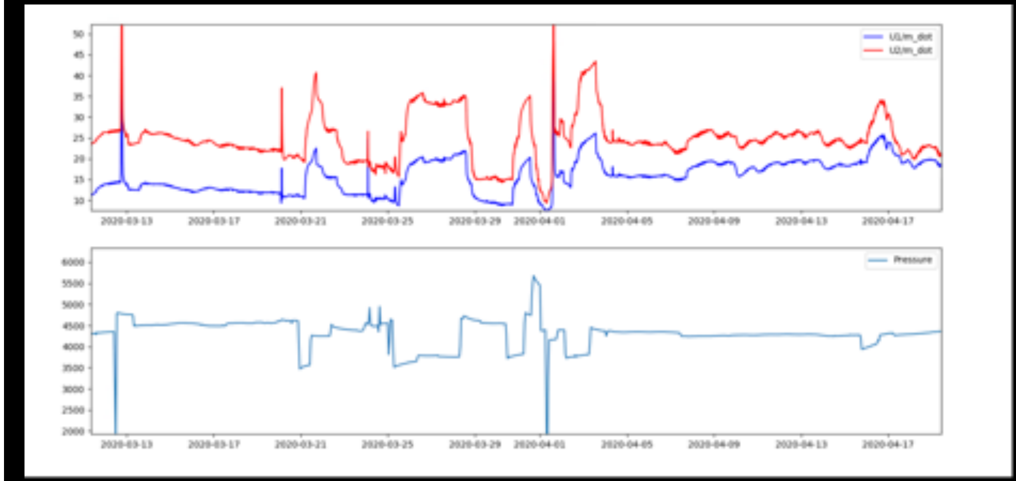
Sample Data

	Upstream 1 (V)	Upstream 1 (°C)	Upstream 1 (°C)	Upstream 1 (°C)	Upstream 2 (V)	Upstream 2 (°C)	Upstream 2 (°C)	Upstream 2 (°C)	Downstream (V)	Downstream (°C)	Downstream (°C)	Downstream (°C)
	Battery (Internal)	Channel 0 - Silicon (Ground)	Channel 1 - Internal	Channel 1 - Silicon (Pipe)	Battery (Internal)	Channel 0 - Silicon (Ground)	Channel 1 - Internal (Disconnected)	Channel 1 - Silicon (Pipe)	Battery (Internal)	Channel 0 - Silicon (Ground)	Channel 1 - Internal (Disconnected)	Channel 1 - Silicon (Pipe)
Date		Position: 0 (m)	Position: 0 (m)	Position: 0 (m)	Position: 89.5014	Position: 89.501472 (m)	Position: 89.501472 (m)	Position: 89.501472 (m)	Position: 915.899	Position: 915.899616 (m)	Position: 915.899616 (m)	Position: 915.899616 (m)
2020-3-20 07:02	13.70770428	4.938476226	-13.96888457	5.005000854	12.80057679	2.829328833	-14.57685658	4.989159862	13.30453651	2.067955431	-15.81212274	5.008954727
2020-3-20 07:12	13.70770428	4.938346511	-14.08342816	5.00367736	12.80057679	2.829902081	-14.95684633	4.988506934	13.30453651	2.067313778	-15.65565946	5.008245799
2020-3-20 07:22	13.70770428	4.937980837	-14.17086166	5.003216842	12.80057679	2.831615761	-15.06201006	4.989473909	13.30453651	2.066471471	-15.82442328	5.007886967
2020-3-20 07:32	13.70770428	4.938048385	-14.36385184	5.003408476	12.80057679	2.829986061	-15.098762	4.988453979	13.30453651	2.066580729	-15.80453992	5.007859328
2020-3-20 07:42	13.70770428	4.938310137	-14.65983434	5.004394295	12.80057679	2.833091678	-15.26488561	4.990595725	13.30453651	2.067561719	-16.01286367	5.008519102
2020-3-20 07:52	13.70770428	4.938249861	-14.76754409	5.005356291	12.80057679	2.833629273	-15.56912424	4.99232125	13.30453651	2.069292546	-16.42720877	5.009255821
2020-3-20 08:02	13.70770428	4.938175648	-15.06723283	5.005904897	12.80057679	2.832191015	-15.87574138	4.992017412	13.30453651	2.069224926	-16.76550417	5.009994316

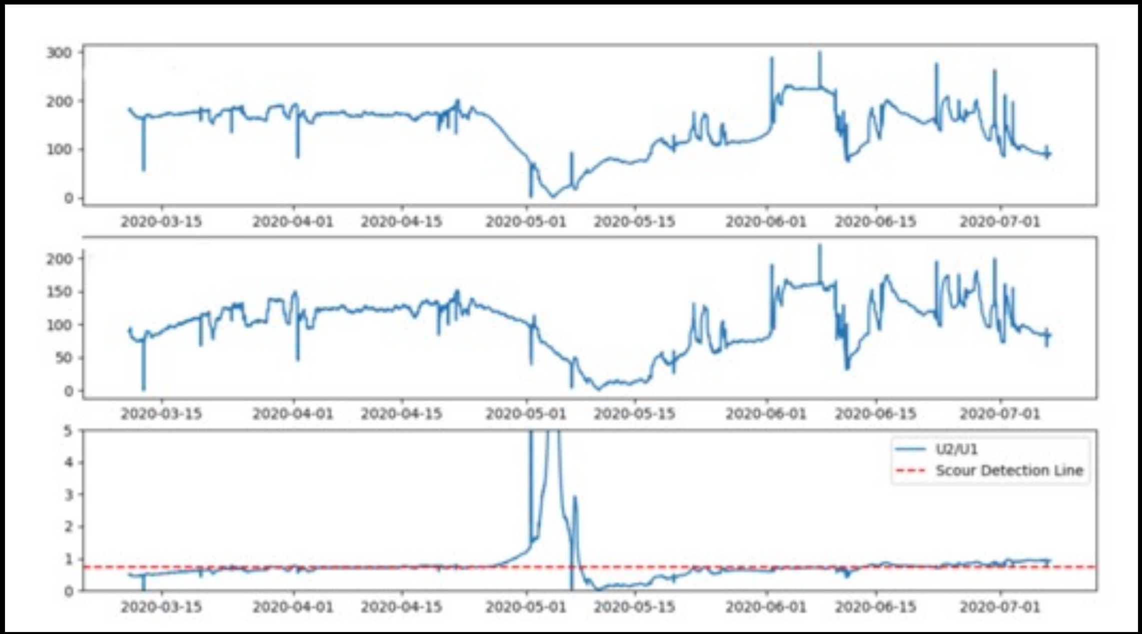
Tongue River Pipeline #1 Sample Data

Data collected every 10 minutes

Software Upgrade (Version 3.0)

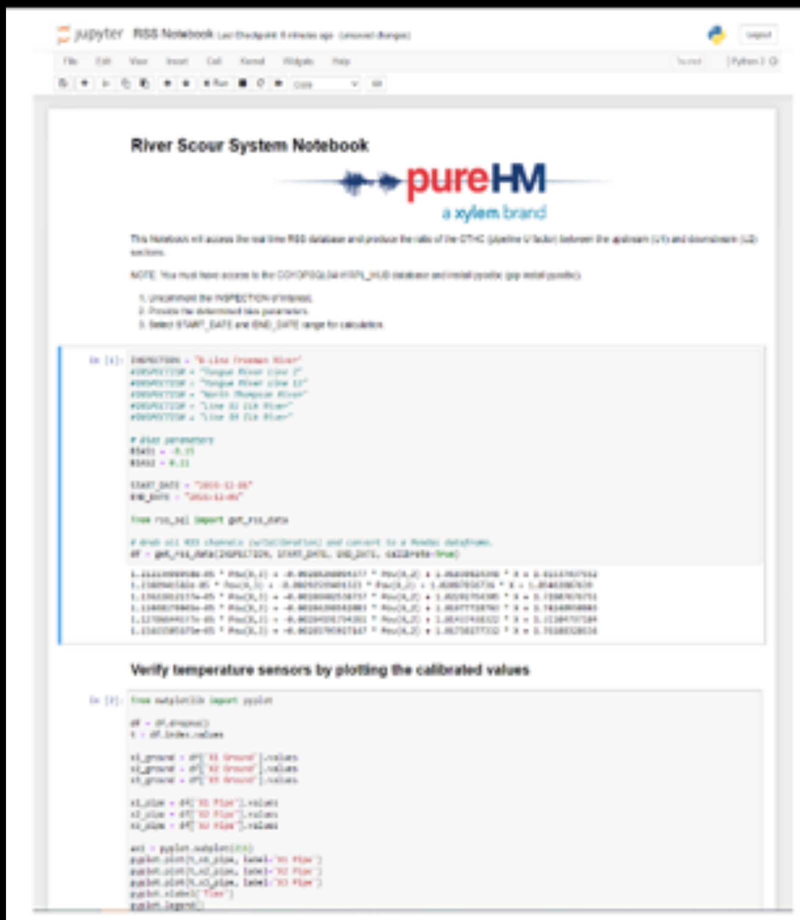


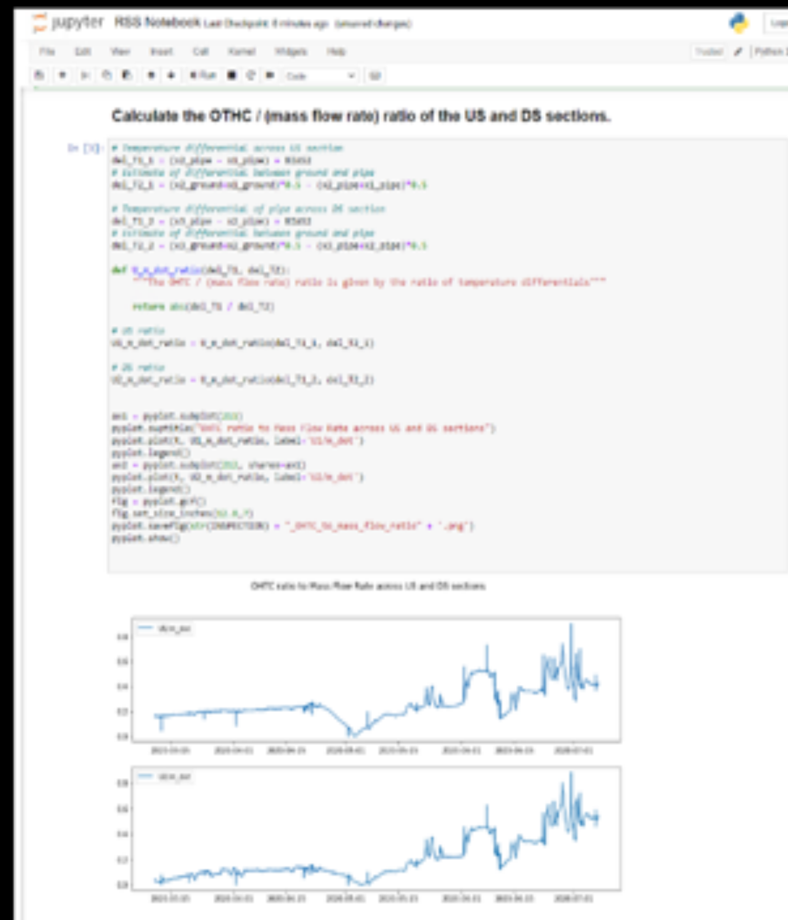
Correlation with SCADA pressure data



Auto bias adjustment and scour detection threshold added

Software Upgrade (Version 4.0)





Incorporation of Jupyter Notebook Source

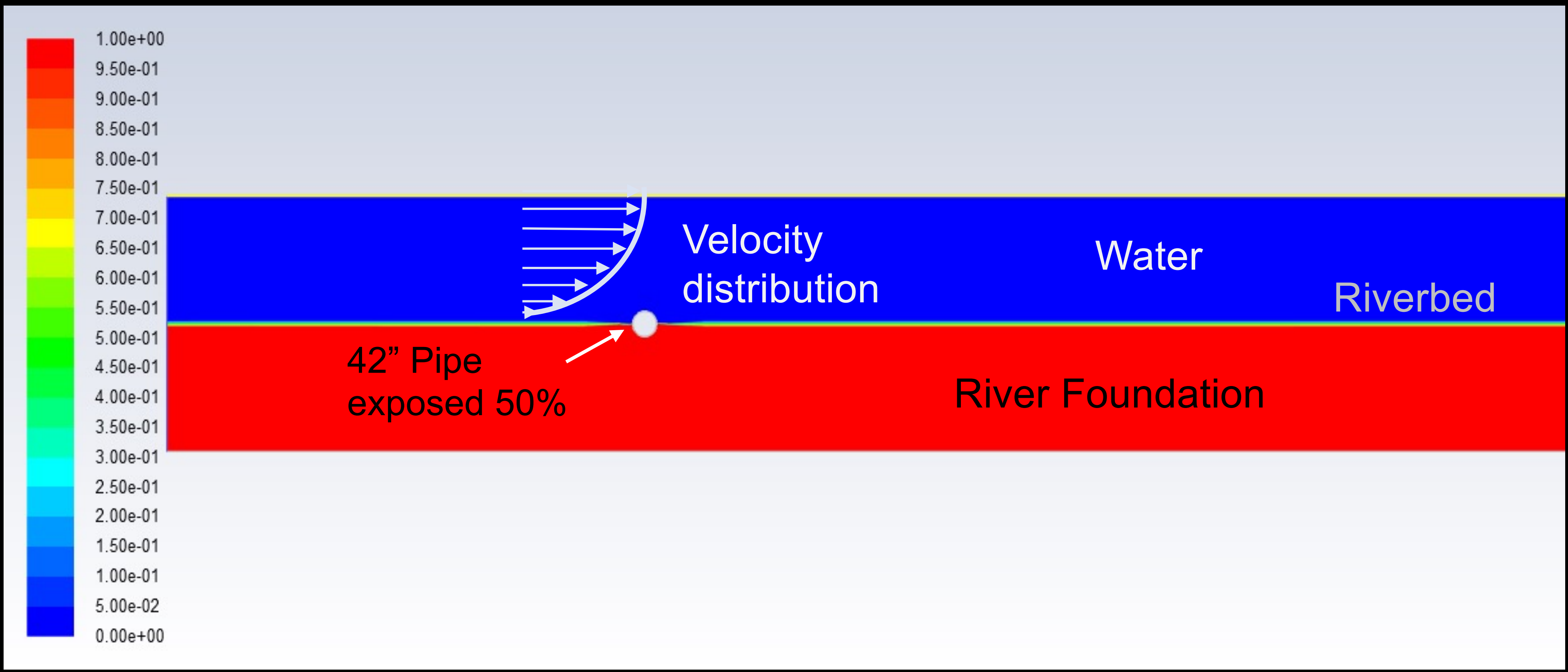
RSS Hardware Upgrade (Version 4.0)

- Camera added to system
- Solar powered
- Satellite communication
- Used as a standalone piece for optimal viewing of the river

RSS Hardware Upgrade (Version 5.0)

- Camera added to system
- Solar powered
- Satellite communication
- Used as a standalone piece for optimal viewing of the river
- More robust steel conduit
- Enhanced perimeter security fencing

Modeling of Vortex-Induced Vibration



Ansys ”Fluent” simulation software

Material/Model Parameters

Pipe (Steel, AISI-1040)

Outside diameter 42’’
Wall thickness 0.375’’
Density 7845 kg/m^3
Elasticity modulus 200 GPa
Poisson’s ratio 0.29
Shear modulus 80 GPa
Tensile strength, Yield 490 MPa
Tensile strength, Ultimate 698 MPa

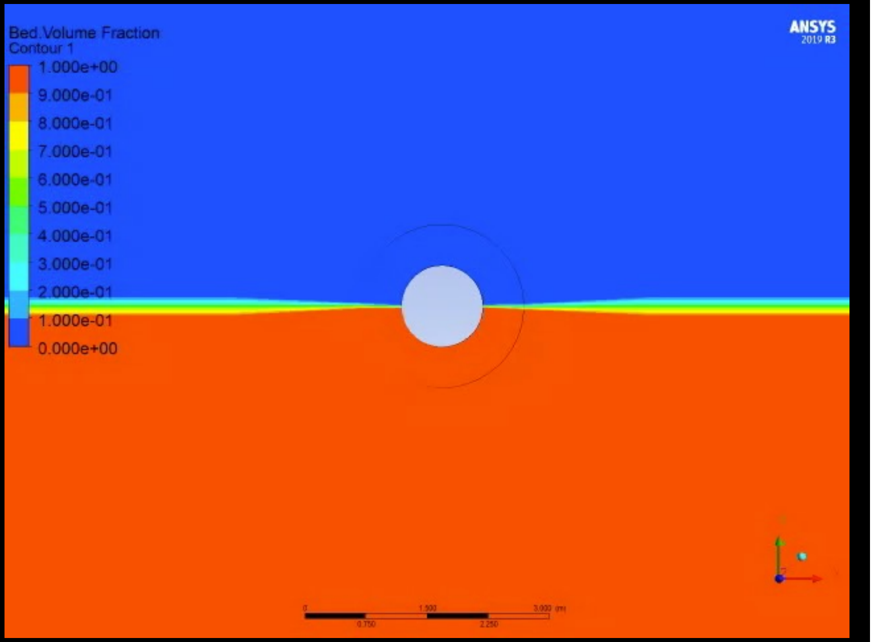
Water

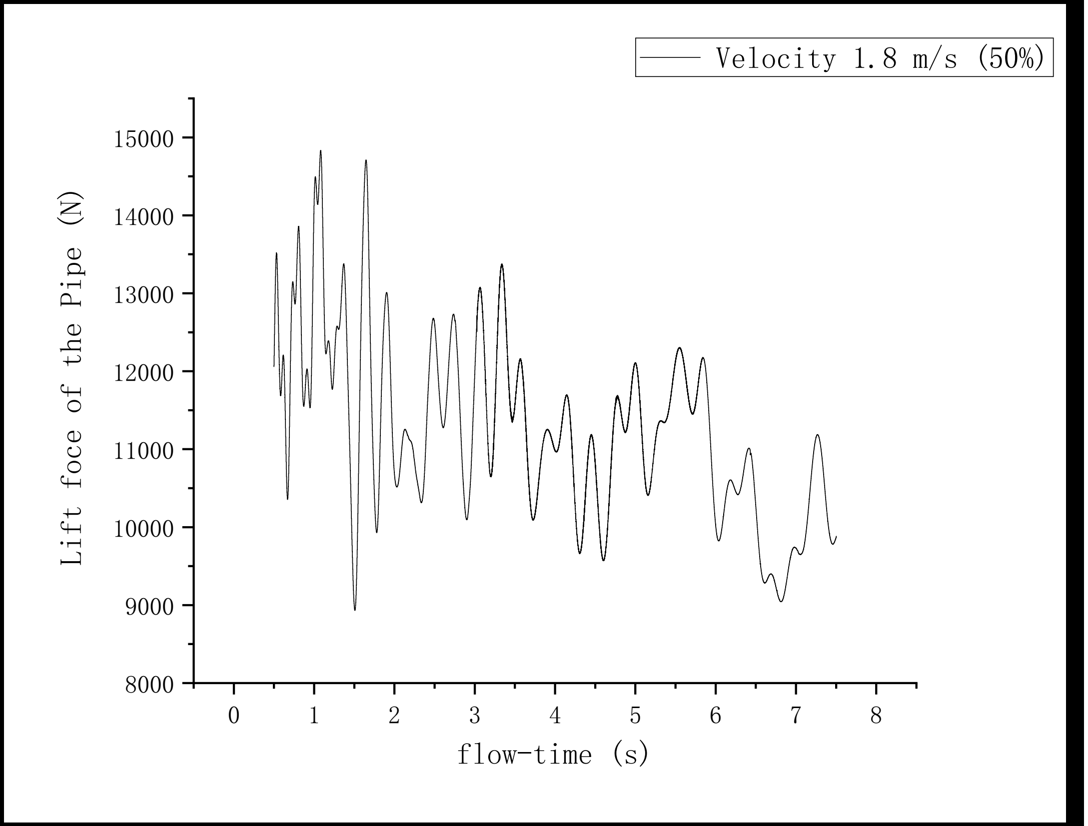
Turbulent Model — k-epsilon standard
Average velocity 1.8 (2.2/2.6) m/s
Density 1000 kg/m^3
Viscosity 0.001 kg/(m·s)
Thermal expansivity 0.000208℃(10℃)
Specific heat capacity 4186 J/(kg·K)

Riverbed (Clay)

Density 1800 kg/m^3
Elasticity modulus 20 MPa
Viscosity 0.23 kg/(m·s)
Poisson’s ratio 0.35

Simulation of Vortex-Induced Vibration

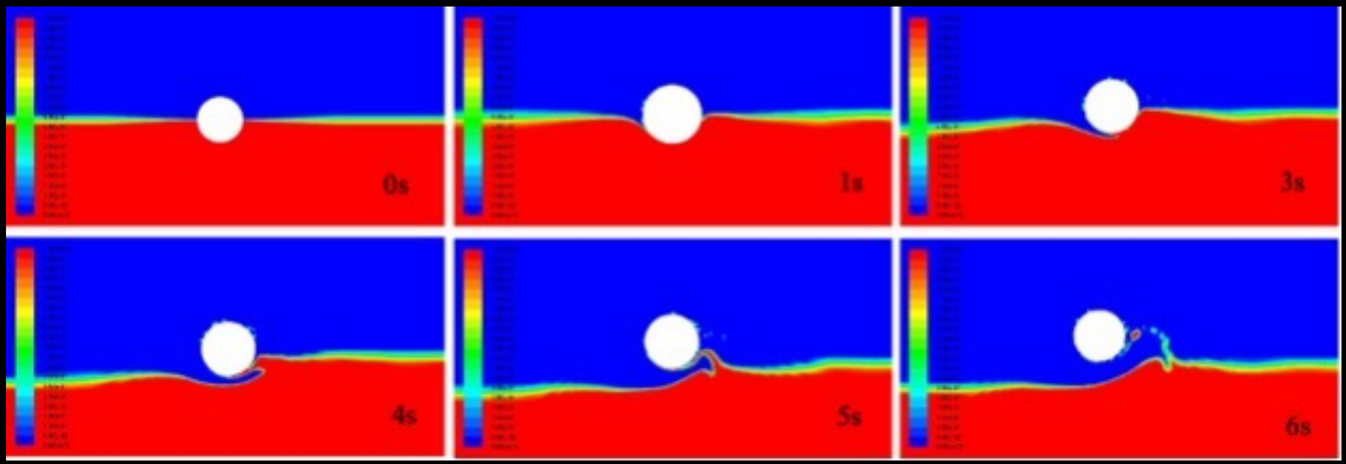




Flow Condition #1 = 1.8 m/sec
50% pipe exposed

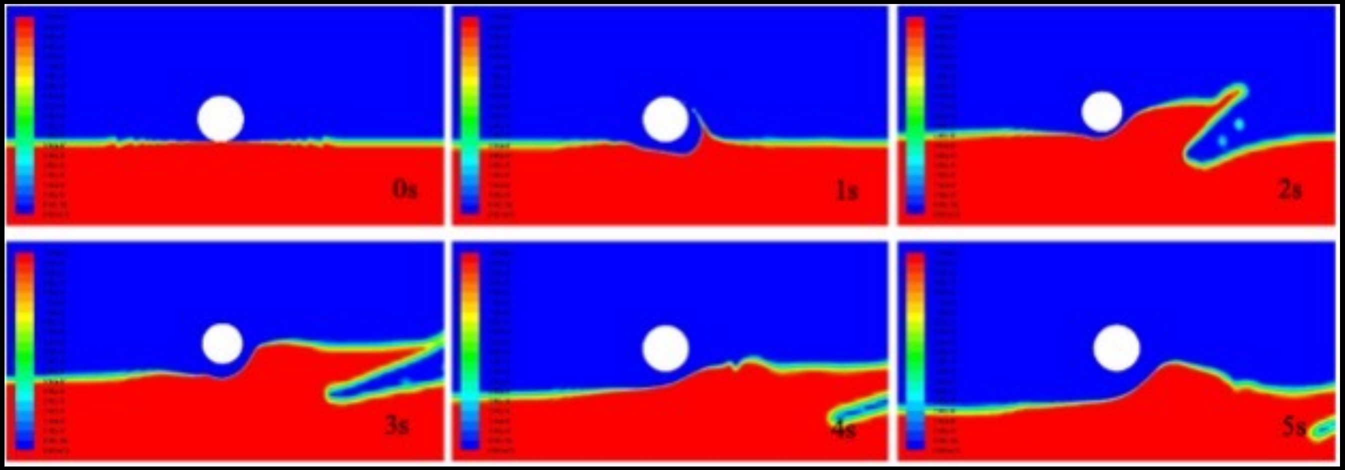
Here, the lift (or drag) value is the resultant force of the pipe under the action of fluid and other external forces. We need to calculate the internal force of the steel pipe based on its the internal fluid pressure and material parameters to determine whether the pipe is damaged.

Simulation of Vortex-Induced Vibration



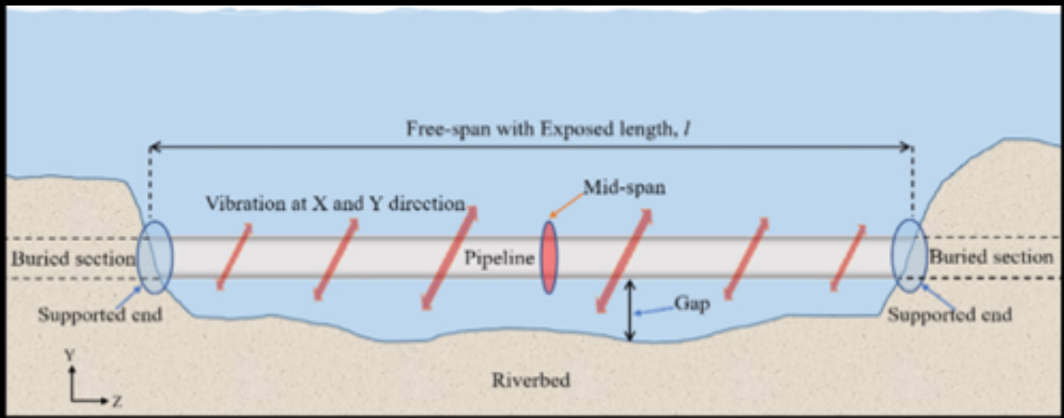
50% exposed
1.8 m/sec flow

100% exposed
1.8 m/sec flow



VIV Observations

- Regardless of the initial exposure rate of the pipeline or the velocity of the fluid, as water flows through the pipeline over an extended period of time, the riverbed soil around the pipeline erodes and disperses eventually resulting in complete exposure
- Exposure rate has a greater effect on the mechanics of the pipe in the lift-direction, while the fluid velocity has a greater effect on the mechanics of the pipe in the drag-direction
- As the exposed length of the oil pipeline increases, the influence of external fluid force on its stress increases, and the contribution of internal pressure to its stress decreases



Results and Conclusions

- Data was collected over an 18-month to 19-month period on four pipelines and 4 months on the vandalized unit at the Freeman River
- Research and field installations indicate that the River Scour Monitoring Systems (RSS) can provide active monitoring for possible river scour, thereby enabling immediate remedial actions to prevent exposure of the buried pipeline
- The RSS system is intended to perform similarly on narrow and wide river systems; however, the impact from seasonal flooding is more of an issue and a threat to pipelines in narrower rivers such as those studied in this research
- Enhanced perimeter security fencing was placed to provide a deterrent to future third-party damage
- A simulation model of an oil pipeline exposed on a riverbed was created and the volume of fluid (VOF) and user defined functions (UDFs) methods in FLUENT were used to study the influence of the pipeline under the VIV of the fluid
- Future research will be aimed at developing models to predict potential future river scour from collected field data

River Scour Monitoring System results will be presented in 2021 and 2022 at selected pipeline industry events (two events in 2020 were cancelled due to COVID-19):

1. 2021 Trenchless Middle East, Dubai, UAE (December 13-14, 2021)
2. 2022 Trenchless Asia, Kuala Lumpur, Malaysia (July 27-28, 2022)
3. 2022 ASCE Pipelines Conference, Indianapolis, IN (July 31–August 3, 2022)

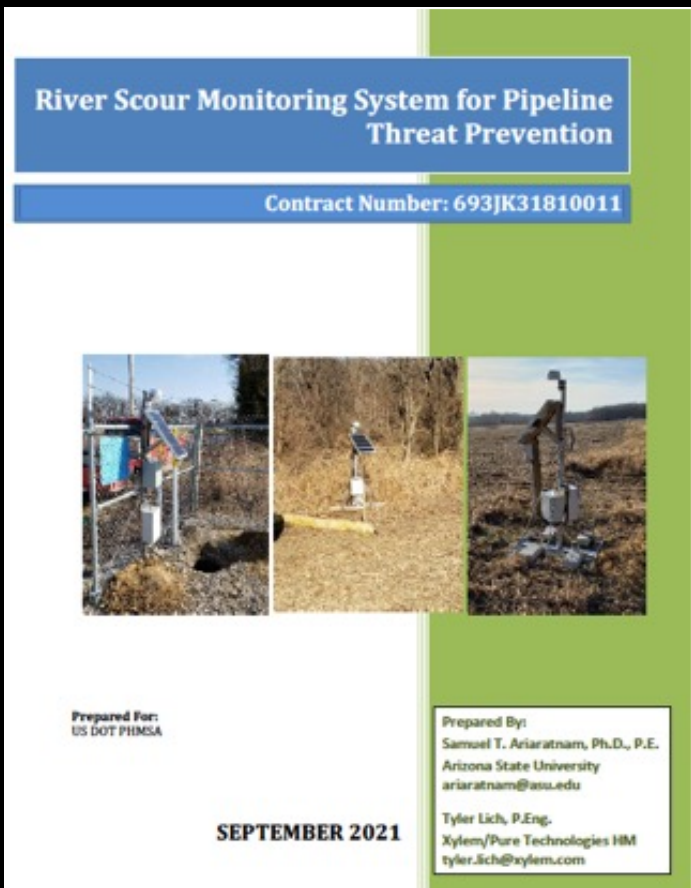
Additionally, results were submitted to technical journals such as *Energies* and *Tunneling and Underground Space Technology (TUST)* for publication consideration

River Scouring Monitoring Systems (RSS) are being presented alongside other PureHM/Xylem services at various trade shows in the U.S., Canada and overseas

Multiple aspects of the technology registered under patents in the U.S. and internationally

Service continues to be introduced directly to pipeline integrity managers and/or technical support groups within oil and gas companies

Please access the project’s Public Page to view the final report and presentation: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THANK YOU

Arizona State University

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