Development of The Navigator:
A smart sensing system to characterize aquatic ecosystems

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Description of research problem and research objectives.

Stream water quality is widely understood by sampling the water that passes across a cross-section through grab sampling or semi-continuous sensors (e.g., optical and wet-chemistry sensors), monitoring water properties at frequencies ranging from sub-hourly to monthly. This type of sampling, referred to as Eulerian, is extensively used but limited due to the sparseness of sites providing a crude understanding of spatial heterogeneity (Krause et al. 2015). An alternative way of sampling, which is rarely used due to logistical challenges, is Lagrangian monitoring, where water parcels are tracked as they move through aquatic systems. Currently, Lagrangian monitoring requires expensive personnel and equipment, creating a major methodological limitation. With the rapid development of water quality sensors and Unhumaned Aerial Vehicles (UAVs) in the last decades, a period now called the "renaissance of hydrology"(Gabrielle 2019), could alleviate the constraints for a Lagrangian reference frame monitoring (Oroza 2013).

Lagrangian monitoring tracks particles as they changes in space and time, and this could help us answer how systems arrive to a present state at specific locations (such as those used in Eulerian monitoring). The integration of existing Eulerian monitoring stations with Lagrangian monitoring can significantly increase our knowledge of where, how, and critically why water chemistry changes in time and space as it moves through river networks. For example, assessing wildfire's impact on water quantity and quality across fluvial networks, i.e., over multiple spatial and temporal scales. While there has been great insight gained from past research on water quality dynamics, they have primarily utilized Eulerian sampling regimes. Such sampling methods often do not address the spatial heterogeneity inherently present in watersheds (Blaen et al., 2016; Krause et al., 2017). To tackle this issue, we developed The Navigator, a floating multiparameter sonde that uses Lagrangian approaches to track solutes, quantity diffused and point sources, and identify areas of accelerated processing within fluvial systems. Briefly, The Navigator is an autonomous drifter, which allows high-resolution sampling of water quality parameters over spatial and temporal scales currently unattainable (i.e., at the sub-minute scale).

This report describes the design of The Navigator and the assembly of its electro-mechanical systems. The report also includes two case studies from the initial prototyping and validation.

Methodology

The Navigator is designed for use in shallow freshwater systems likes rivers, lakes, and streams. The spherical form was chosen to minimize resistance and maximize the cross-sectional area to flow. The Navigator is designed to sit low in the water (i.e., it's hydro-statically stable) and reduce the wind drag. The Navigator contains sensors, thrusters, cameras, batteries, LTE and Bluetooth, GPS, and mayfly datalogger. Onboard sensors for temperature, conductivity, dissolved oxygen, ORP, and pH protrude from the bottom of the sphere. LTE communication coupled with a visualization portal can transmit and display data in real-time and allow easy retrieval.

During the design process of the electro-mechanical system, the protype was modified and desired functionalities were added with the advancement in the development. Fig 1 shows an exploded diagram for the assembly of The Navigator. The dimension of the sphere is 10 inches and it weighs around 2kg, allowing for portability and accessibility for monitoring in remote environments. The first protype included three onboard sensors operating at 2-minute intervals along with GPS and LTE connection, with the estimated operating time of around 36 hrs. (without any solar power). The run time can vary depending on the sensor's head, thruster incorporation, battery size, and solar panel size. There was also an open-source smartphone application, "Thingsview," which was used for the real-time feed, removing the need for an operator moving next to The Navigator.

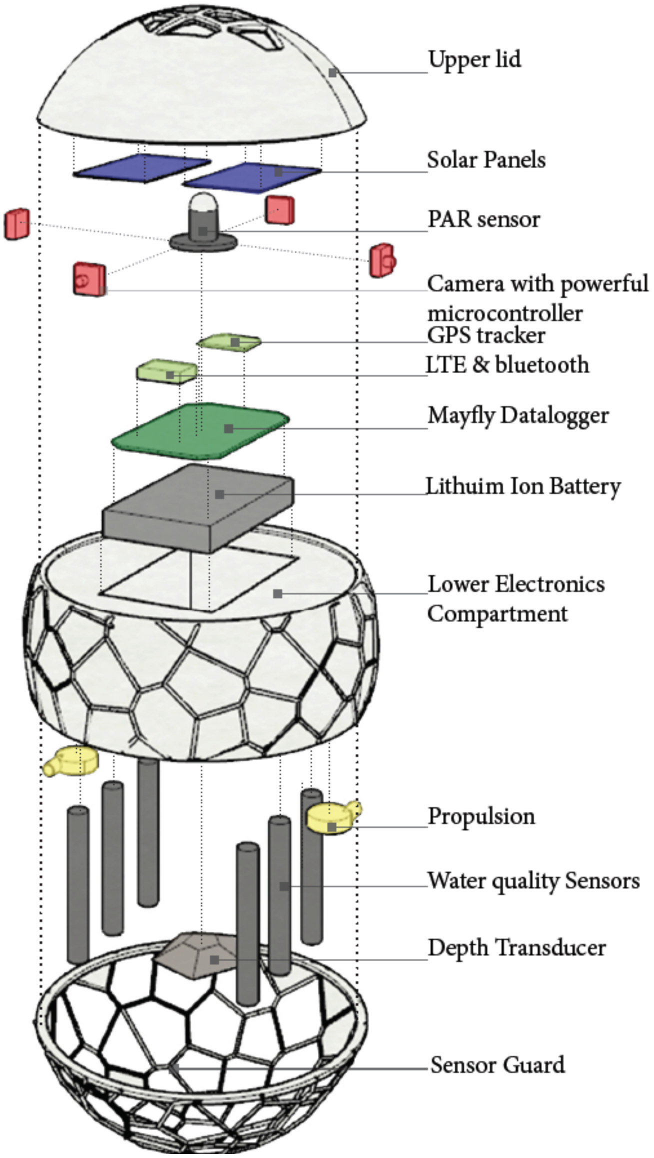


Figure 1: The Navigator’s exploded diagram with details

Note: The protype is not fully developed as of July 2021. The shell design, electronics with LTE, GPS, and sensors were completed and validated. The current effort is to incorporate propulsion, depth sensing, camera, and PAR sensor.

The advanced protype, which is currently beign developed, will incoporate the thruster, camera, and depth transducer that will make it spin out of entrapment areas and increase the reach distance that it can travel drastically. The exploded diagram in Fig 1 shows how all the components fit together. The sphere is divided into three parts; the upper lid is transparent, allowing the sunlight to recharge the battery via solar panels and to collect the photosynthetic light levels using PAR sensors. It also houses cameras to collect the trapped location footage, which helps in maneuvering of thrusters. The middle layer comprises of datalogger, LTE, GPS, antenna, sensors circuit, and a battery. And the third layer has a cage-like structure not only allows the water to pass through the sensor, depth transducer, and thruster but also protects from direct impacts.

The sphere was 3D modeled using Rhino software and was further optimized using Grasshopper programming software to reduce the thickness of the shell, which minimizes 3-D printing time and material cost and to optimize the strength by using the grid pattern. The shell can be 3-D printed in 3 parts using the widely used Acrylonitrile Butadiene Styrene (ABS), as it has greater strength, durability, and resistance against sunlight.

As the protype is still under development and evolution, all the 3-D design files, software source code, and the controlling Android application will be publicly available via a methods paper that will be published soon, enabling easy assembly, programming, and replication for the interested users.

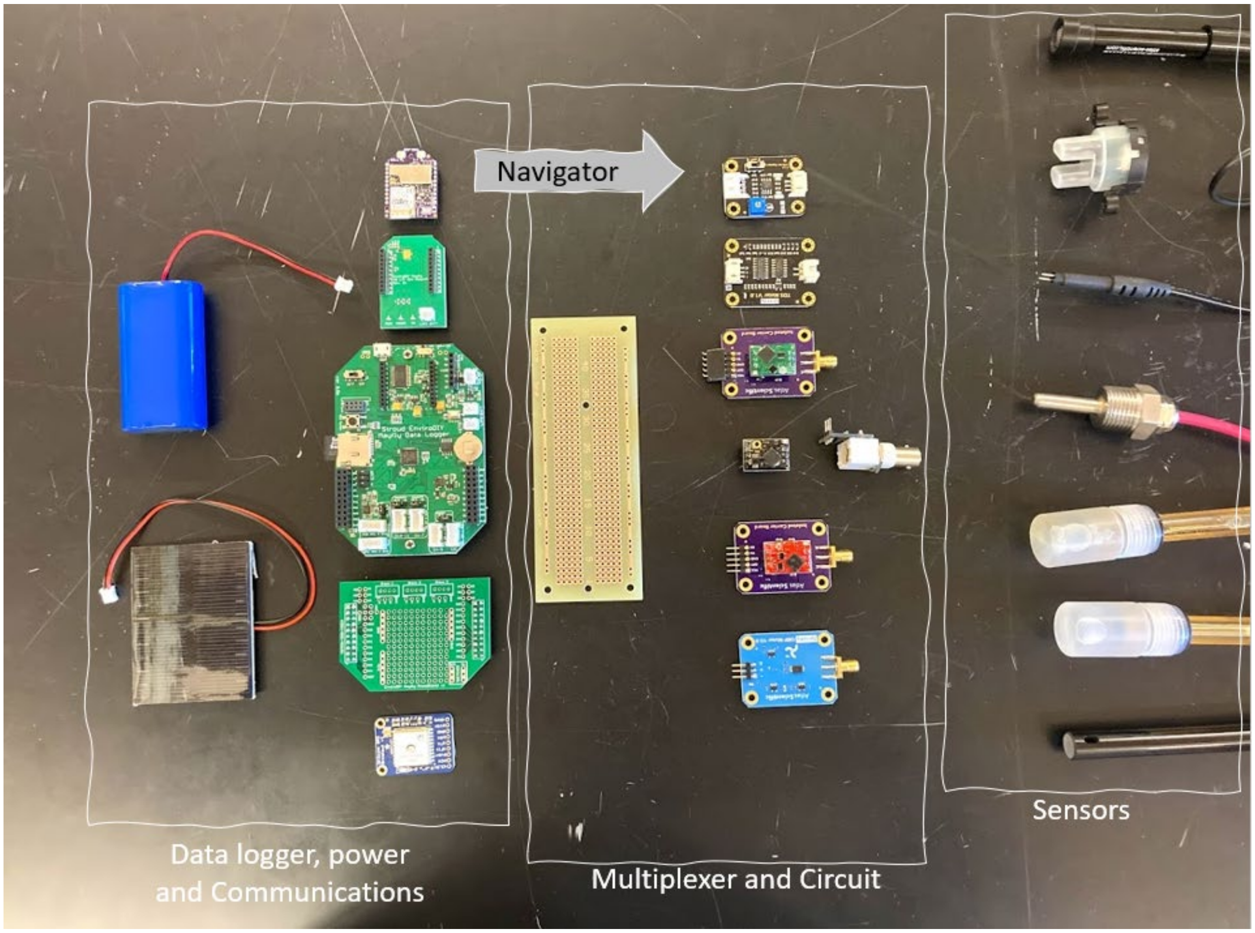


Figure 2: The Navigator electronic Schematic: Mayfly datalogger, communications, multiplexer, sensors circuit and Sensors.

Table 1: The Navigator component description.

Component	Example	Description
Solar Panel	0.5 W solar panel	Option for bigger solar panel for longer and higher frequency runs.
LTE & GPS tracker	EnviroDIY GPSbee	The EnviroDIY GPSbee is an easy way to add GPS capability to any device that is compatible with the standard Bee footprint.
Data logger	Mayfly Data Logger	The EnviroDIY Mayfly Data Logger is a powerful, user-programmable microprocessor board that is fully compatible with the Arduino IDE software.
Battery	Lithium Ion Battery Pack - 3.7V 4400mAh	This lithium-ion pack is made of 2 balanced 2200mAh cells for a total of 4400mA capacity. The cells are connected in parallel and spot-welded to a protection circuit that provides over-voltage, under-voltage and over-current protection
Sensors	Atlas Scientific	Atlas Scientific provides the sensor head from pH, temperature, conductivity, ORP & DO.
Sphere Casing	3D Printed using ABS filament	Ender 5 pro 3d printer using ABS filament.

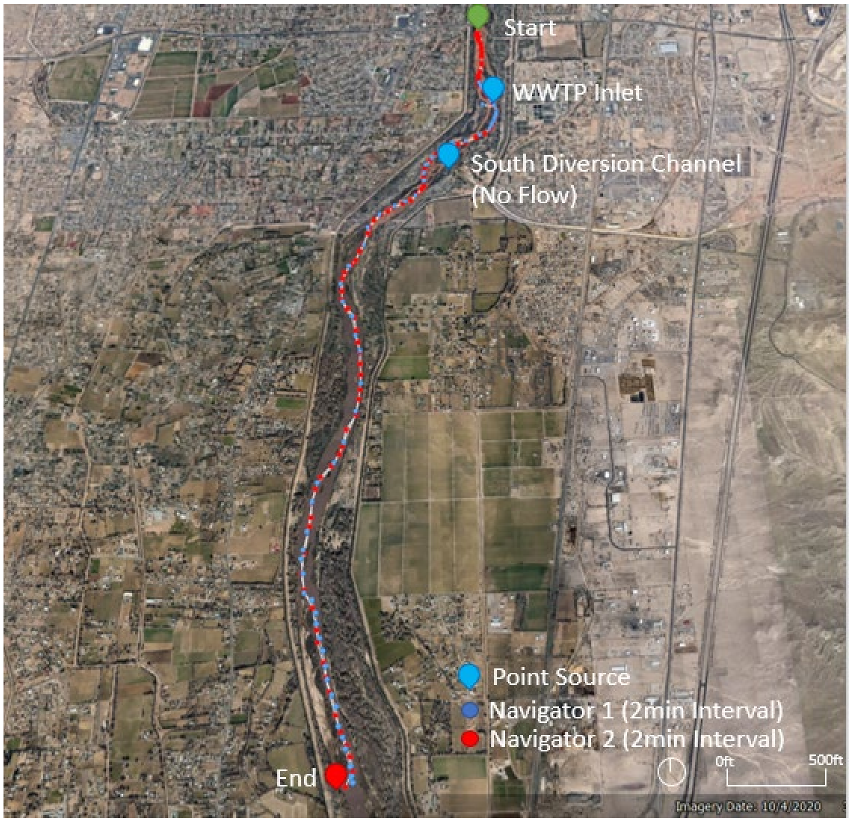
Case studies:

The Navigators were tested in real-world environments to test the robustness and ability to accommodate a diverse set of applications for multiple end users.

Rio Grande- ABQ WWTP Stretch

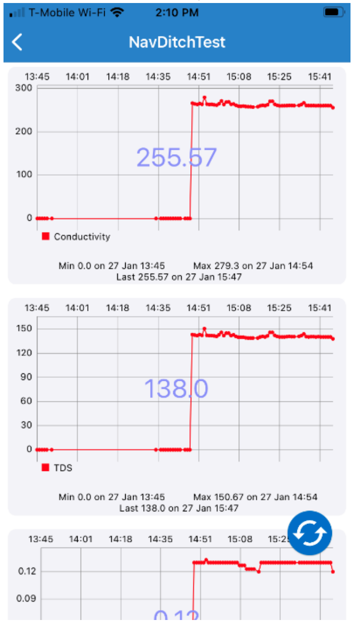
This study took place along 5.3 miles of the Middle Rio Grande River (a reach along ABQ's WWTP Effluent outlet), from Rio Bravo Bridge to the I-40 bridge. Major point sources along this reach includes the ABQ WWTP and a south diversion channel which was running dry during the day of the study. The flow of the Rio Grande is heavily modified in this section from its natural state by the WWTP effluent and urban storm runoff from the south diversion channel, resulting in alteration of flow and changes in water temperature.

The study took place on March 10, 2021, with an average flow of 550 cfs as measured by the USGS 08330000 Rio Grande Guage at Central Ave, Albuquerque, located approximately 5 miles upstream from Rio Bravo bridge. We deployed two Navigators and a YSI Exo attached to a kayak to measure temperature and specific conductivity. The Navigators were followed by us on the kayak as the current protype lacked the thruster system. All the sensors were configured to collect measurements at 2-min intervals along with the GPS data. Sensors were synchronized, calibrated, and run side by side before the deployment to ensure the high quality of the datasets.



Realtime data on the Thingview App

GPS Data
Temperature Sensor
Conductivity Sensor

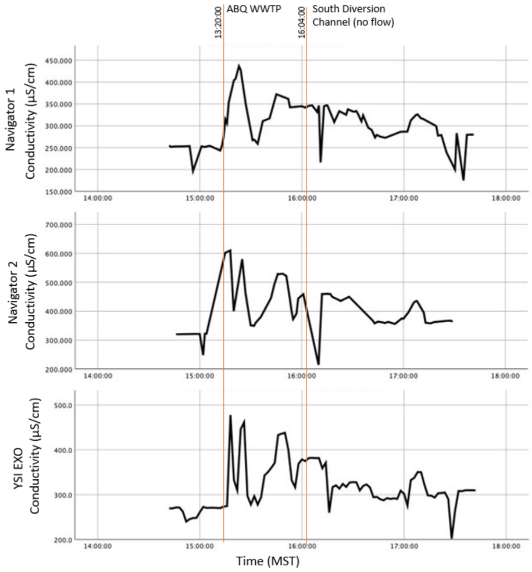


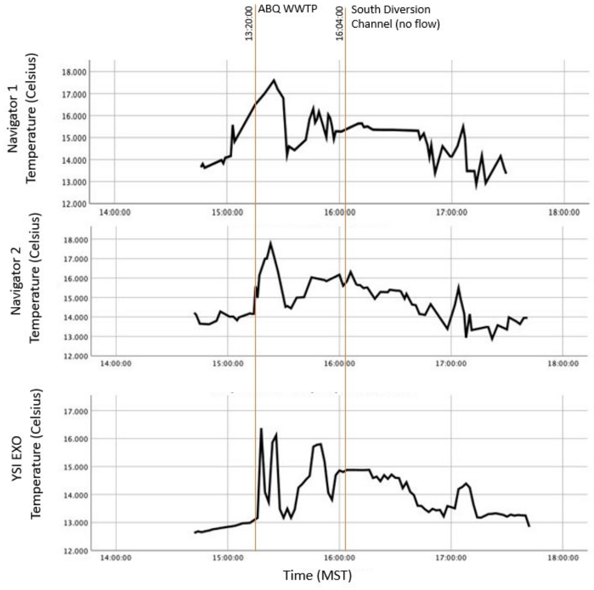
■ Conductivity

Min 0.0 on 27 Jan 13:45 Max 279.3 on 27 Jan 14:54
Last 255.57 on 27 Jan 15:47

■ TDS

Min 0.0 on 27 Jan 13:45 Max 150.67 on 27 Jan 14:54
Last 138.0 on 27 Jan 15:47





Temperature Datasets

Conductivity Datasets

Figure 3: Time-Spatial series data of conductivity and temperature along the Albuquerque WWTP- Rio Grande corridor form Navigator 1, Navigator 2 and EXO (attached to kayak) with GPS trajectory. A screenshot on the top right corner from the Things View App for real-time monitoring.

The average temperature and conductivity of Rio Grande upstream of WWTP were 282 uS/cm and 13.4 °C respectively. We saw a sharp increase in the conductivity and temperature as soon as they passed through the WWTP effluent outlet, with conductivity going over 400 uS/cm and temperature over 17 °C as shown in Figure 3. Increased temperature and conductivity spikes indicate potential disruption to aquatic species. The temperature and conductivity gradually decreased after the WWTP effluent source. The velocity of the Navigators were fairly equal, averaging around 0.78m/sec computed using GPS data. This study could help to understand the impacts of point source like WWTP effluent on river's discharge and water quality.

Valles Caldera (Tracer Experiment):

A conservative tracer test was conducted in the East-Fork Jemez River, located in the Valles Caldera, NM. The stream section for the tracer test had a total length of 450 m flows along a highly meandering course through a floodplain. In approximately 15 L of stream water, 736g of NaCl were premixed, and the solution was added as a pulse and spread out over the entire width of the stream to reduce the distance until which complete cross-sectional mixing of the tracers was reached. The breakthrough curves (BTC) of the tracer, as well as the temperature and pH of the river water were measured at an Eulerian monitoring station located 440m downstream of the injection site, and equipped with a multiparameter YSI's EXO 3 probe with temperature, pH, and conductivity sensor heads with a temporal resolution of 2 min. A Navigator with a temperature, pH, conductivity, and GPS sensor was deployed 10m upstream of the injection point. All the probes were calibrated and run side by side before and after the deployment to ensure the high quality of the datasets.

The Navigator's conductivity value spiked to 148.6 uS/cm at the tracer injection point, from 86.5 uS/cm measured 10m upstream of it. The conductivity dropped to around 100 uS/cm as soon near a small pool located a few meters downstream of the injection point, indicating tracer dilution. This indicates the potential of The Navigator to identify spotty and changing physicochemical properties of streams. By correlating other parameters like velocity, temperature, and pH, The Navigator can also identify hot spots along the study length.

Injection Mass (NaCl): 736gm
Stage 1'2"
Total Reach: 460m
Injection time: 11:36 am
Navigator Start: 11:36am
10m upstream from the injection site.

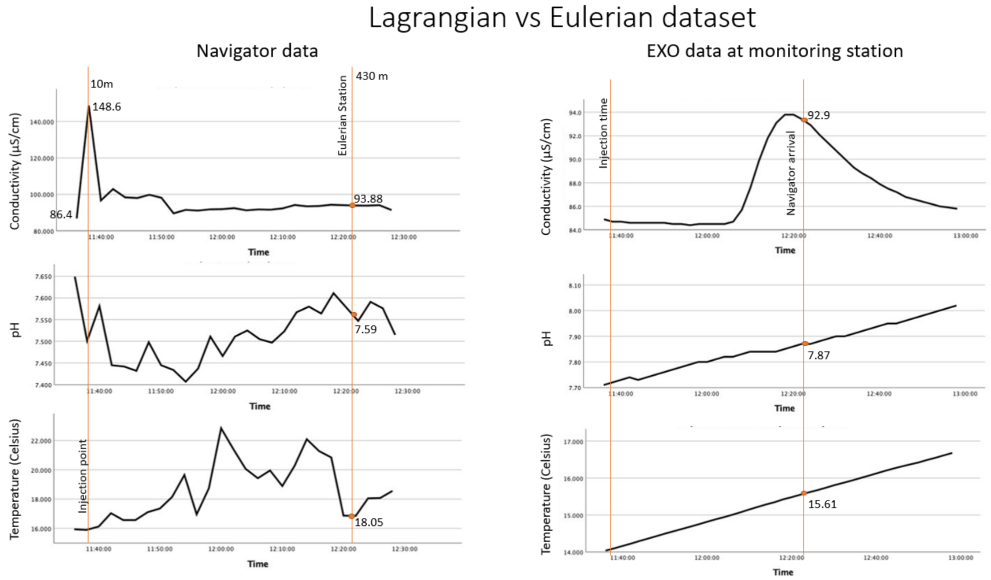


Figure 4: Time-Spatial series data of Conductivity, pH and temperature along the East-Fork Jemez river form Navigator with GPS trajectory and a time series datasets form EXO at Eulerian station.

Results:

In this report, we introduced a new, soon-to-be fully open-source, small-sized, and low-cost drifter that can be used for near-surface water quality monitoring in real-time. Most of the housing can be printed using a 3D printer, and 3D files, software source code, and the visualization application will be made publicly available through a peer-reviewed manuscript, enabling people to easily assemble and modify the programming to meet specific needs. We tested The Navigator in real-world settings in contrasting stream orders, successfully validating its performance in terms of adaptability, mobility, and stability. Additionally, we discovered new challenges during our initial testing resulting in further evolution for longer deployment and easier retrieval. The Navigator is developed based on the convergence of emerging cutting-edge technologies and using those technologies to tackle ever-increasing water challenges. With the power of convergence of emerging technologies like sensor development, quantum computing, networks, 3D printing, robotics and drone development, The Navigator will be easily adaptable and modifiable.

Who will benefit from your research results?

Aquatic sensor development not only opens a niche of opportunities associated with the creation of local start-up companies but also generates pioneering data that will help us continue to position New Mexico as leaders of scientific developments in hydrology, biology and ecology, and multiple engineering disciplines including civil and environmental, mechanical, chemical, and biological, and computer science. The data gathered by smart sensors will support better and more enforceable water management practices. The data generated from The Navigator can benefit researchers, practitioners and water agencies such as New Mexico Environment Department, the United States Bureau of Reclamation, the United States Army Corps of

Engineers, and the USGS. The rugged, arid, and highly erosive terrain of New Mexico, which creates numerous ephemeral and intermittent fluvial networks, and the river infrastructure that we have built to survive in the desert provide ideal conditions for scientific inquiry and unmatched testbeds for technological development like The Navigator. Not surprisingly, the leading water sensor (YSI and Sea Bird Scientific) companies which test their sensors in our state have coined a statement that briefly summarizes our unique strengths and opportunities: "if it works in New Mexico, it will work anywhere!".

How have you spent your grant funds?

Account Description	Proposed	Actual
Under Grad Student Salaries	2000	2,962.49
Supplies/equipment/products	4100	4126
Conference Travel (Covid restrictions)	1,000	0.00
Total:	7,100.00	7,091.55

Presentations you have made related to the project.

UNM CWE Mini Conference 2021

Upcoming AGU 2021

Upcoming NM WRRI's 66th Annual New Mexico Water Conference

List publications or reports under preparation.

A publication will be submitted to ASLO's top-rated journal Limnology and Oceanography: Methods by Spring 2022.

List of students assisted you with your project.

Tzion Castillo and Trevor Amestoy, undergraduate students from the School of Engineering at UNM. Jancoba Dorley and Justin Nichols, graduate students from the Center for Water and the Environment at UNM.

Special recognition awards or notable achievements because of the research including any publicity such as newspaper articles, or similar.

UNM Civil eNews on July 13,2020 :

https://civil.unm.edu/news/2020/07/two-graduate-students-in-dr.-gonzalez-pinzons-team-win-research-grants.html

Information on degree completion and future career plan.

I am planning to complete my PhD in Interdisciplinary Engineering at the University of New Mexico by December 2022. After graduating plans on opening a side startup that stimulates water technology innovations and focuses on transitioning research and development to impact. My plans to contribute to water-related innovations that can lead to revolutionary technological advances that will enable communities to better satisfy their needs.

Citations:

Blaen, P. J., Khamis, K., Lloyd, C. E. M., Bradley, C., Hannah, D., & Krause, S.(2016). Real-time monitoring of nutrients and dissolved organic matter in rivers: Capturing event dynamics, technological opportunities and future directions. Science of the Total Environment, 569–570, 647–66

Boano, F., Harvey, J. W., Marion, A., Packman, A. I., Revelli, R., Ridolfi, L., & Woerman, A. (2014). Hyporheic flow and transport processes: Mechanisms, models, and biogeochemical implications. REVIEWS OF GEOPHYSICS

Buytaert et al. (2014), Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development, Frontiers in Earth Science (2), doi: 10.3389/feart.2014.00026.

Fountain. (2020), The drought that has gripped the American Southwest since 2000 is as bad as or worse than droughts in the region over the past 1,200 years, a new study finds., The New York Times (2), ISSN: 0362-4331

Heisler, J., Glibert, P. M., Burkholder, J. M., Anderson, D. M., Cochlan, W.,Dennison, W. C., Dortch, Q., Gobler, C. J., Heil, C. A., Humphries, E., Lewitus, A.,Magnien, R., Marshall, H. G., Sellner, K., Stockwell, D. A., Stoecker, D. K., & Suddleson M. . (2008). Eutrophication and harmful algal blooms: A scientific consensus. Harmful Algae,8(1), 3–13.

Kirchner, J. W., Feng, X., Neal, C. and Robson, A. J. (2004), The fine structure of water quality dynamics: the (high-frequency) wave of the future. Hydrol. Process., 18: 1353-1359. doi:10.1002/hyp.5537.

Krause, S., Lewandowski, J., Grimm, N. B., Hannah, D. M., Pinay, G., McDonald,K., Marti, E., Argerich, A., Pfister, L., Klaus, J., Battin, T., Larned, S. T., Schelker, J.,Fleckenstein, J., Schmidt, C., Rivett, M. O., Watts, G., Sabater, F., Sorolla, A.,& Turk, V.(2017). Ecohydrological interfaces as hot spots of ecosystem processes. WATERRESOURCES RESEARCH, 53(8), 6359–6376

Krause, Stefan, , Jörg Lewandowski, , Clifford N. Dahm, and , Klement Tockner. 2015. “Frontiers in Real-time Ecohydrology – a Paradigm Shift in Understanding Complex Environmental Systems - Krause - 2015 - Ecohydrology - Wiley Online Library.” 2015. https://onlinelibrary.wiley.com/doi/full/10.1002/eco.1646.

Oroza, Carlos. 2013. “Design of a Network of Robotic Lagrangian Sensors for Shallow Water Environments with Case Studies for Multiple Applications - Carlos Oroza, Andrew Tinka, Paul K Wright, Alexandre M Bayen, 2013.” 2013. https://journals.sagepub.com/doi/10.1177/0954406213475947.

Environments with Case Studies for Multiple Applications - Carlos Oroza, Andrew Tinka, Paul K Wright, Alexandre M Bayen, 2013." 2013. https://journals.sagepub.com/doi/10.1177/0954406213475947.

Sobota,D. J., Compton, J. E., McCrackin, M. L., & Singh, S. (2015). Cost ofreactive nitrogen release from human activities to the environment in the United States.ENVIRONMENTAL RESEARCH LETTERS, 10(2).

Val H. Smith, Samantha B. Joye, &Robert W. Howarth. (2006). Eutrophication ofFreshwater and Marine Ecosystems. Limnology and Oceanography, 51(1), 351.

van Sebille et al. (2018), Lagrangian ocean analysis: Fundamentals and practices, Ocean Modelling (121), 49-75, doi:10.1016/j.ocemod.2017.11.008.