Physicalization of Colorado River Basin Snowpack Data

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ABSTRACT

We developed an interactive exhibit for navigating through snowpack data via a sink interface and a digital map display. This project addresses challenges a local radio reporter who covers the Colorado River Basin identified around communicating water and snowpack data to the public: It's hard for people to connect snowpack data to lived experiences and to conceptualize relative differences in water data in the context of a shifting climate. We created a series of maps of snowpack data, as a percent of historical averages, for SNOTEL stations across the Western United States, from 1985 to 2018. To view these maps, a user turns the left faucet/knob on the sink to scroll through time and the right faucet/knob (which we affectionately call the "wetness meter") to scroll through relative snowpack size. The goal of our project is to captivate people by requiring them to interact with a sink in order to uncover "hidden" data. We found that snowpack data is complex, with a daunting range of metrics that makes the data difficult to access and understand. We found that although a sink interface has many affordances and connotations that can complicate how people perceive the data, exhibit is an intriguing way to spark people's curiosity. With more time, we would like to test SNOWSINK out with users to see how they perceive the experience and how well they understand the snowpack data.

Keywords: physicalization, environmental data, tangible displays, education outreach

1 INTRODUCTION

1.1 Overview of water issues and data

Water – and its scarcity— dominates the psychology and policy of the Western United States. Watersheds cross geopolitical and cultural boundaries and are vital to industry, agriculture and residential life. The Colorado River Compact [1], which binds seven states, is highly dependent on how much snow falls in the Rocky Mountains. As a historically low snowpack hits the Southwestern U.S. in 2018 [4], the dynamics of water systems and relevant data like snowpack and streamflow remain obtuse and inaccessible for general audiences.

We spoke with Luke Runyon, radio reporter at KUNC in Greeley, Colorado, who covers Colorado River issues. He identified two major challenges in his work communicating water and snowpack data to the public: (1) data is often given in terms of relationship to historical averages, which is hard to connect to on-the-ground-impacts and lived experiences; (2) as the baseline of what is normal shifts due to climate change, communicating long-term historical trends and fluctuations year over year is tricky.

Two major sources of water systems data are snowpack and streamflow. We chose to focus on snowpack data, which is collected from a network of 858 snow telemetry (SNOTEL) stations across the West. SNOTEL stations collect all kinds of data – temperature, wind speed, soil moisture – in addition to snowpack data. The data is maintained by the Natural Resources Conservation Service's National Weather and Climate Center [12], which is part of the U.S. Department of Agriculture. Snowpack is measured with snow pillows, which are plastic sacks filled with fluid that gets displaced under the weight of snow. You can view the data through NRCS's interactive map [9] and bulk download custom data reports [8].

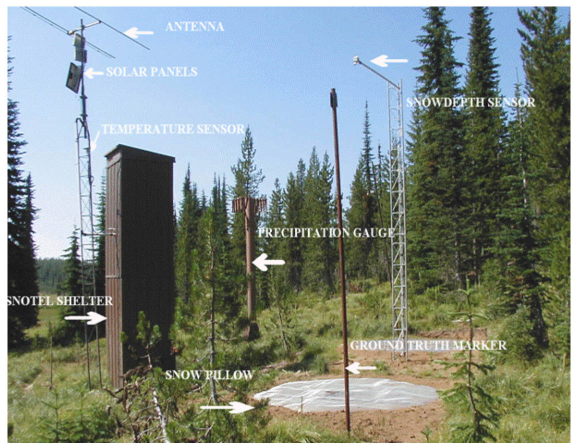

Figure 1: Typical SNOTEL station. Credit: NRCS/USDA.

There are many ways to measure snowpack, and we chose snow water equivalent, which is how much water you would get if you were to instantly melt the snow. This data can be presented as the absolute amount or as a relative measure, such as the percent of the historical average from 1980 to 2010. We chose to use the latter, because we felt this was more meaningful and allowed us to compare across stations and mountain ranges. To further complicate things, SNOTEL data is reported daily and monthly. We chose to use the monthly data for March, because March is typically the snowiest month in the Rocky Mountains and is a critical month for predicting the watershed's activity over the rest of the year. This complexity is compounded by the fact that scientists recalculate what "normal" mean every 10 years (the baseline average used to be 1970-2000, then 1980-2010, and will soon be 1990-2020). Data is also reported at several geographic levels: individual stations, sub-basins, basins, sub-regions and regions.

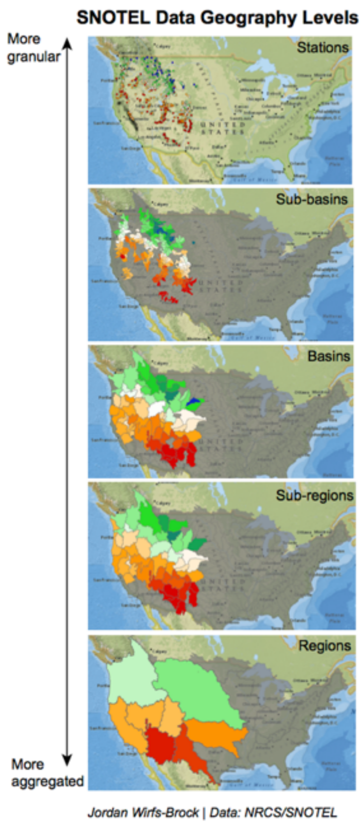

Figure 2: Geographic levels that SNOTEL data is reported. We ultimately chose to display station-level data, because this would provide more visual change between the different views.

The way the data is described is extremely obtuse – just listing the name of the metric is a mouthful that requires a compound clause: Snow water equivalent measured at SNOTEL stations across the Western United States, as of the end of March, represented as a percent of the historical "normal" values from 1980 to 2010. This exemplifies the problem we are trying to solve: How do we make this data accessible, understandable and engaging?

We tackled this problem by dipping into the world of data physicalization, drawing from the traditions of museum design, data visualization and sonification. Our goal is to design for general audiences, inviting them to spend more time interacting with the data through a physicalization than they would a digital visualization. If people have to turn physical knobs on a sink in order to explore the data, perhaps they will remember the data better and be more actively engaged with the information.

2 Related Work

2.1 Snow and water visualizations

Typical methods for visualizing snowpack data by academic centers and government agencies include choropleth maps, heatmaps, categorical maps. Here are some examples from the U.S. Geological Survey [14], NWCC [9] and the University of Nebraska-Lincoln's Drought Monitor program [13] display stream flow, drought and snowpack data:

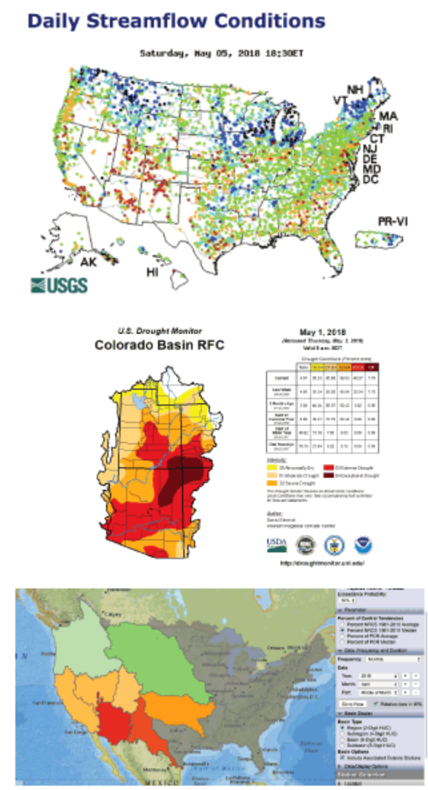

Figure 3: Examples of how academic and government organizations are visualizing water and snow data. Top: USGS daily streamflow conditions throughout the U.S. [14]. Middle: Drought Monitor Colorado Basin report [13] Bottom: NWCC interactive map of snowpack data [9].

These visualizations tend to be comprehensive in terms of displaying the most recent data, but the interfaces for users to look at historical data or compare how the data is changing over time are clunky. We chose to focus on improving this interaction by making it easy to navigate forward and backward in time in order to allow the viewer to make meaningful comparisons. In terms of Schulz's concept of a design space for visualization tasks, [6], we wanted to focus on **exploratory analysis** (for the user) by **navigation** through **high-level features** of the data to identify **temporal** and **spatial** relationships over **multiple** views of the data. Because our work is for communication purposes, we are invoking Robert Kosara's ideas about presentation modes: "Two criteria are specific to presentation techniques, but not helpful (or even counterproductive) for analysis: memorability and engagement." [3]

2.2 Data physicalization

To maximize memorability and engagement, we are drawing on the tradition of data physicalization. Work by Terrenghi et al [7] has shown that when people complete puzzles using physical pieces versus digital pieces, physical pieces produced more satisfaction. As outlined in Jansen et al's, "The Opportunities and Challenges of Data Physicalization," interacting with physical objects provides opportunities for intermodal and multi-sensory activities and leverages our "perceptual exploration skills." [2] Yet designing and building physicalizations requires complex processes, and it is difficult to animate physical objects with high fidelity. For this reason, we chose to do a hybrid design, employing a physical interface with a digital visualization.

We are also inspired by Matt and Lisa Bethancourt's (known as Mouse & the Billionaire) work with curiosity, confusion and physical installations. Their nY-station [10] and Zip Coda [11] installations both explore sonified data through physical interfaces that are intriguing and confusing: a patch-board/surveillance system and a desk with information hidden inside drawers. People experiencing the exhibits have to explore, and it's not clear what they are looking at or what the goal of the exploration even is. This process of blended curiosity, intrigue and confusion is intended to lead to enhanced engagement. However, in the Bethancourt's installations, it's very hard (maybe even impossible) to reverse engineer the embedded data signals and derive insights from the underlying data. We wanted to draw on some of their elements of interactivity, while making the insights in the data more accessible. That's why we have a somewhat obtuse interface (the sink) with a straightforward visualization (the map).

2.3 Sonification and sound design

Luke Runyon, the radio reporter we are working with, has experimented with using the sounds of water to illustrate scientific concepts. In his recent story on the effects of dust on the rate of snowmelt [5], he used slow and rapid dripping sounds as audio illustration for melting rate. The sound design of our installation reproduces this idea.

3 Design Decisions

We built an interactive exhibit for general audiences to use a sink interface to navigate through historical and current snowpack data for measing stations across the U.S. Two knobs/handles on the sink control time and the size of the snowpack that is being shown. The sink interface is unexpected, intriguing and conveys the idea that this is data about water. As the user turns the water on, he or she sees stations where more and more snow fell. The physical interface was built using cardboard, potentiometers and an Arduino controller. A Processing script scans through a five-by-five grid of pre-generated images (created in Python). Here's a schematic of the project design:

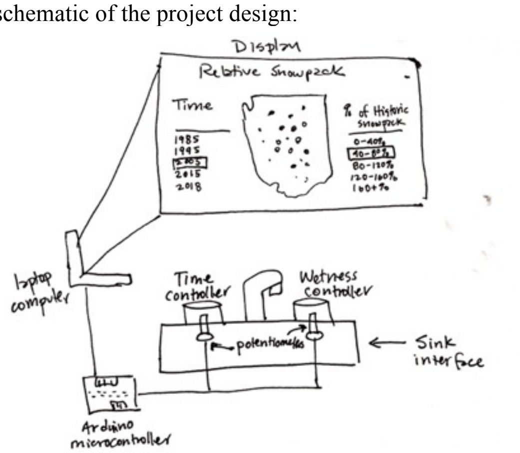

Figure 5: This diagram shows the basic schematic of our project.

3.1 Data selection

Selecting which snowpack data to use in our exhibit wasn't trivial. We had to decide about geographic level, time level—both the time period over which the data was collected (i.e. monthly versus daily) and which time periods to include, snowpack metric (depth, snow water equivalent, etc.), absolute versus historical comparison (and whether do a comparison against the mean, the average, or the "normal" amount from 1980 to 2010 or 1970 to 2000). In short, there were a lot of decisions that affected both the design of the visualization and how a user will interact with and interpret it. We ultimately decided to display:

- Data at the station level, displaying point locations of individual SNOTEL stations; our rationale for this is that there is more difference from view to view, which appeals to the salience of the "position" channel. This level of granularity also provides more visual interest when a user navigates through the years and snowpack ranges.
- Snow water equivalent, because this is a concept that is both meaningful for hydrology and relatively easy to explain.
- As compared to 1980 to 2010 "normal" average snowpack, because based on our discussions with Luke Runyon this is a common way to describe the data.
- Monthly data as of the end of March, because March is generally a snowy month and is important for the annual forecasts of water flows.
- Data from 1985, 1995, 2005, 2015 and 2018 (most recent year of data available). Because we were troubleshooting the interaction, we used discrete buckets on our dials, and wanted to start with a manageable number, which is why we have five categories. Ideally, in future versions of this exhibit, we would show every single year so that people can see fluctuations year-to-year and understand that individual years aren't necessary reflective of longer term trends. We also considered showing a five-year average, but decided against this because it is difficult to explain to a viewer. Another potential solution would be to select notable years and highlight then with annotation.

3.2 Visualization design

Our visualization were created in Python with Pandas and the Cartopy/Geopandas/Geoplot packages, written and implemented as a Jupyter Notebook. We chose to make a map of the locations of the individual SNOTEL stations colored on the scale:

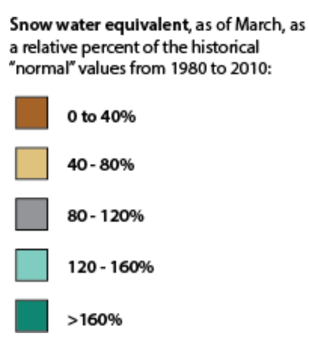

Figure 4: We based our color ramp off of Color Brewer's 5-step divergent option. We modified it by selecting a darker grey, because this was more visible when viewed on its own (more on that below). This color ramp is evocative of the dry/wet dichotomy we are trying to emphasize with the snowpack data. We chose equal intervals, rather than basing our ramp on statistical distribution, because this was more intuitive, and because we were mapping many years (so each year had a very different distribution of data).

We chose a simple map – state outlines with a white fill – to reduce chart clutter and make the colored SNOTEL stations stand out more. (Note that this is a departure design that the NWCC uses.) We chose to show the state outlines to help orient the viewer. We restricted the view to just the Western U.S. (where the SNOTEL stations are) to maximize the screen space of the relevant data – although this does mean we don't have a nice familiar U.S. map outline. (We also dropped Alaska – so sorry Alaska! The authors hate how Alaska always gets excluded, but we were under a time crunch creating this map and Geoplot doesn't support embedded displays.)

Here's what the visualization looks like for March 2018, if we were to show all of the snowpack levels (0 to 200+%) on one view:

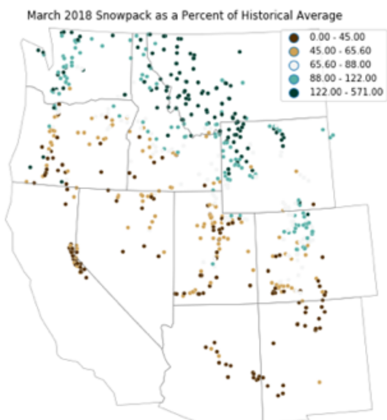

Figure 5: Example of a map with *all* SNOTEL stations (with data – nulls have been dropped) snow water equivalent data, as a percent of historical "normal" values, for March 2018. (Note that the color ramp is slightly different here than in the visualizations we used in our final display.)

However, the purpose of our design is to "reveal" the various data views and filters as a user interacts with the handles on the sink. This adds a curiosity/mystique element to the data. To support this interaction, we created views that showed only ***one*** category of snowpack (i.e. 0 to 40% percent, or 120 to 160% of the historical snowpack as a time). This may go against some tenants of data visualization design, but we were intentionally employing ambiguity as a design and interaction feature to lure users in and engage their sense of exploration. Here's what a single frame looks like (2005, 0 to 40% of historical snowpack):

Figure 6: An example of one of the views from our display.

On these displays, SNOTEL stations that are in a different range are shown as empty circles. In order to discover how much snow fell at those stations, users must continue to explore further.

To generate the visualizations, we had a five-by-five grid of possibilities (five years, five relative snowpack sizes). We wrote a Python script to generate these images as a single batch.

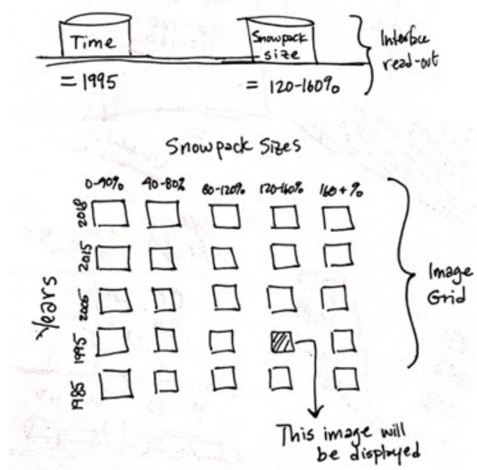

Figure 7: This image shows the relationship between the setting on the sink's knobs and the map that is displayed.

3.3 Interface design

We constructed a sink interface that uses two knobs – representing the faucet controls – to navigate through time and relative snowpack size. We considered using a single handle/faucet, which is similar to many common sink designs, and might have been more realistic. However, we wanted to give the user more options to control the data display, so went with a two-knob design.

Because this is a proof of concept exhibit, we made the sink out of cardboard. We considered using a child's toy sink, which would have let us run water through it, or salvaging a sink from a junkyard, but ultimately decided against these options for time and cost considerations. In future versions of this design, we could pursue these options more fully.

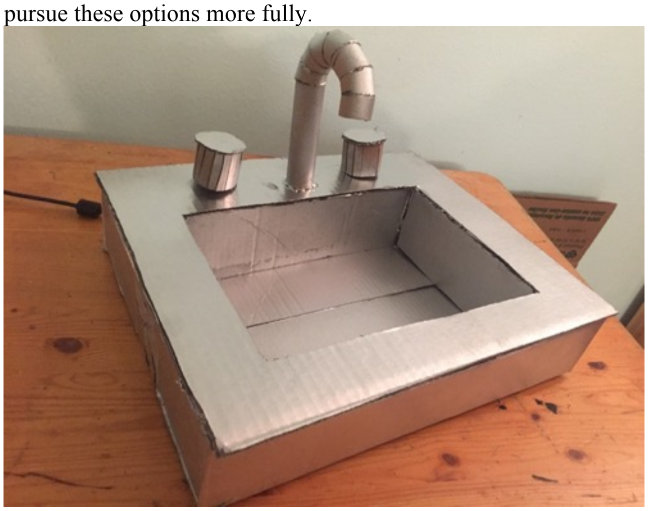

Figure 8: The sink interface, built out of carboard. The knob on the left scans through the years and the knob on the right scans through the relative snowpack size ranges.

Figure 9: The sink interface with components attached through the back that is then connected to a computer that displays the visualization.

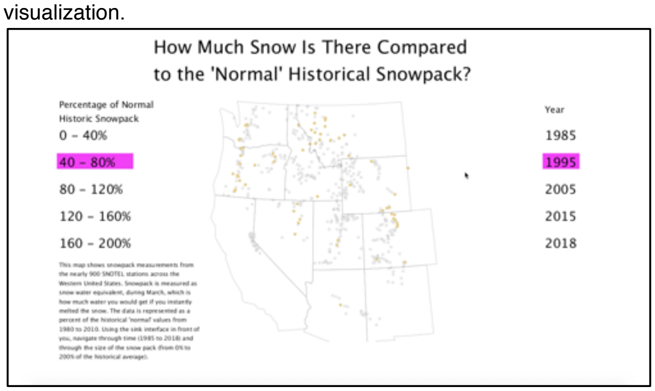

Figure 10: Visualization displayed on computer that responds to the knobs being turned on the sink interface.

The sink's knobs are attached to potentiometers that read the position of the knob as an analog electrical signal. That signal is then converted into a digital signal and read into an Arduino microcontroller, and we wrote code to determine the steps/buckets of the knob positions in C++. We wrote the code to display the appropriate images and text in Processing. One downside of an analog potentiometer is that it lacks feedback for the user. That is, they can't tell when they have stepped to another category (except by visual feedback). In future versions of this design, we might experiment with a rotary encoder.

As a user scrolls through the data with the sink's knobs, the year and relative snowpack size (i.e. 40 to 80% of historical average) are highlighted on the screen. Although much of the data is obscured by the design, the use can see labels for the possible years and relative snowpack sizes that are available, inviting more interaction.

3.4 Sound design

Using the convention Luke Runyon developed in his recent radio story about dust and snowmelt rate, we also chose sound clips (from a slow drip to a rushing stream) to communicate which snowpack percentage (0 – 40% all the way to 160+%) the user is currently viewing. You can listen to these sound clips on our Github page.

4 Discussion

Our sink interface was engaging and pushed us to think about interaction in a new way. We did not have time to test it out with users but would like to get feedback on our design to improve it in the future (and hopefully create something that Luke Runyon can use at engagement events around water issues). If we had more time, we would also pursue these additional design ideas:

- Have more granularity on the time controller (ideally a user could see all available years of data, one year at a time).
- Use a real sink.
- Expand multi-sensory representations. We explored sound, but right now the sonification is iconic, not actually generated by the data. We could create a sonification where the rate of drips actually corresponds to the relative size of the snowpack being displayed. We also considered having additional senses reinforcing the relative size of the snowpack being displayed, like water coming out of the faucet or light that increases in intensity.
- We would like to project the visualization display on a wall, so that the experience is more immersive (and not tied to a small screen).
- Combining this quantitative data with qualitative data, like stories that Luke Runyon has collected of people remembering particularly wet or dry years, talking about how changes in water systems have affected their lives).
- Pairing this data visualization display with a model of a SNOTEL station, so that as people explore the SNOTEL data they can also understand how it is collected.

We found that this design direction is a promising one that we would like to explore further.

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