Project Title

Understanding high mountain aquifers to source drinking water in the Sagarmatha National Park.

List all project participants. Include their title and affiliation.

PI - Professor Kirsten Nicholson Ball State University (BSU)
Co-PI - Professor Klaus Neumann BSU

Collaborators:
Dr Joshua Gruver BSU
Dr Bangshuai Han BSU
Professor Subodh Sharma Kathmandu University (KU)
Mr Prayon Joshi KU
Mr Lakpa Sherpa NGO Action for Nepal

Collaborators with independent funding:
Professor Misa Nishikawa BSU
Dr Steven Hall BSU

Students:
Emily Hayes PhD candidate BSU
- Ms. Hayes contributed $3000 towards her travel costs through external funding.
Smrita Acharya PhD candidate BSU
- Ms. Acharya contributed $1000 towards her analytical costs through an internal BSU grant.
Chase Cobb MSc student BSU
- Ms. Cobb will contribute $800 towards her research costs through an internal BSU grant.
Anusha Pandey MSc student KU
Ishan Subedi Undergraduate student KU
Simon Baniya Undergraduate student KU

Report Start Date: 03/16/2021
Report End Date: 07/10/2022
Please note that a preliminary report was initially submitted in April, 2022, but an extension was granted until after the field expedition in May 2022.

Project Location and Geologic Setting

All work will be performed in the villages of Phortse (2022) and Lobuche (2023), Sagarmatha National Park, Nepal. Phortse is a farming village located at 3840m in the Khumbu Valley in Nepal (27.84965°N / 086.74966°E). In Phortse the work will be carried out primarily on farmland and in sparse rhododendron forest and will cover an area of approximately 400m x 600m. Geologically, the region comprises of high grade metamorphic units (predominately schist, gneiss and leucogranites) with glacial till ranging from sparse to thick. Lobuche is a small
settlement near Mount Everest in the Khumbu region of Nepal. It is one of the last overnight stops with lodging on the "trail to base camp" (27.95890°N / 86.79080°E). In Lobuche the work will be carried out almost entirely on open alpine fields and/or hills comprising of glacial till and glacial moraines. In Lobuche the work will likely cover an area of approximately 300m x 300m.

Location map showing water quality sample sites from 2016 to 2019 as solid triangles. The locations of Phorste and Lobuche are both shown. The SNP boundary is the solid black outline and the dashed line delineates the SNP Buffer Zone in the south. The inset map shows the location of the SNP relative to the countries of Nepal, India and China.

The village of Phorste in 2018. The ERT survey will cover the village, with 4-6 NW-SE trending arrays and 2 intersecting N-S arrays.

Note: all photos are taken by the PI unless otherwise noted.
Map showing the location of Phortse village (lighter green area outlined in red) taken from Google.

The village of Lobuche in 2022. The ERT survey will cover the village, with 4-6 E-W trending arrays and 2 intersecting N-S arrays.

Google Image of Lobuche and the Khumbu Glacier. Lobuche village is outlined in red.
**Humanitarian Need and Benefit**

Most years, over 30,000 people visit the Mt. Everest region of Nepal (note that during the Covid pandemic the number of tourists was significantly reduced). With a resident population of ~6000, limited power and water, extreme high altitudes, cold temperatures, and low local incomes, the region suffers terribly from environmental degradation. Over 12 metric tons of human waste per year is carried downhill from the base camps and dumped at lower elevations into open unlined pits. In addition, the region has limited facilities, fewer than 4% of septic systems are lined or sealed, and open defecation is common. Combined, these practices pose a significant health risk due to contamination of the water supply. This project proposes to help two communities in the SNP: Phortse and Lobuche. These communities have a resident population of approximately 300 (Phortse) and 50 (Lobuche) people, however, each year thousands of tourists, porters and guides visit these communities. As such, the issue of potable water effects both the local and the itinerant populations, with long-term implications significantly impacting the resident population.

**Project Goals and Objectives**

The primary goal of the project is to improve access to drinking water and improve drinking water quality for the two communities. In order to achieve this goal there are six main objectives:
1. Delineate community aquifers,
2. Quantify seasonal recharge and discharge,
3. Assess location of locally built filtration system,
4. Map the geology of the basins, including structural geology, rock types and basin fill,
5. To help develop long term strategies for water management and help mitigate the long term effects of climate change and minimize potential earthquake risk.

**Progress Toward Goals and Objectives**

In 2019 we hosted a meeting with the Phorste community committee. The meeting was deemed a success and we started planning for fieldwork in 2020. Most supplies were purchased, students were recruited, and tickets were purchased. The trip was canceled due to Covid. We were not permitted, by the university, to travel in 2020 or 2021. During this time we kept in contact with Lakpa Sherpa from Action for Nepal, the Phortse community and Professor Sharma from Kathmandu University.

In May 2022 we were able to travel to Nepal for a three-week field season. The university did not grant us permission to travel until January 2022 and we were not allowed to take undergraduate students on the trip. In addition, our flights were not approved (and tickets could not be purchased) until March 2022.

Our field team comprised of 6 faculty (Gruver, Han, Hall, Neumann, Nicholson and Nishikawa) and 6 students (Acharya, Baniya, Cobb, Hayes, Pandey and Subedi). Unfortunately, Professor
Sharma, Lakpa Sherpa and a representative from the National Park Service were unable to join us in the field due to the national elections.

The BSU team leaving BSU on May 4. From L-R: Neumann, Nishikawa, Gruver, Hayes, Lange (technician – non travelling), Nicholson, Han, Cobb and Misbach (student driver – non travelling). Note that Acharya met the team in Nepal.

> 400kg of luggage at Kathmandu airport.

Our travel dates were May 4 to May 28. We arrived in Kathmandu on May 6 and were met at the airport by our guide, Mohan and his family. We were joined by the Nepali students in the afternoon of May 6, we all flew to Lukla on May 7, and began trekking on May 8. We hired a team of porters from our guide’s village who met us in Lukla with our generator and petrol. In total we had ten porters who carried approximately 400kg of gear. In Namche Bazaar (May 11) we were given our second sampling permit. The main Kathmandu office of the National Park Service grant the initial sampling permit, but it then has to be formally approved by the chief warden in Namche Bazaar. Some years this has taken 5 full days due to political wrangling which is beyond our control. However, we arrived in the region a few days before the national elections which worked in our favor as the permit was granted immediately.
The research team on our first day of trekking and research. From L-R: Nishikawa, Acharya, Cobb, Hayes, Han, Hall, Mariwan (our guides daughter and trainee guide), Gruver, Mina (our guides wife), Neumann, Pandey, Nicholson, Subedi and Baniya.

Note: The Pasang Lhamu Gate is a memorial to the first Nepali (Sherpa) woman to summit Mt Everest.

Our team arrived in the village of Phorste on May 12. May 13 was the day of the national elections. This worked in our favor for many reasons, including the fact that most residents were in Phorste on May 13. On May 13 part of our team went to the voting area and invited all local residents to a community meeting which was held on the evening of May 13. The rest of the group ran the first ERT lines across the southern lower slopes of the village. The initial ERT lines were short, only 14 nodes, as we ran into some problems with planted fields. Over the following week we managed to run 6 ERT lines ranging from 14 to 84 nodes. The problems encountered will be discussed in detail below.
Our work was conducted during the pre-monsoon dry season. 2022 had been particularly warm and wet up until the end of April. By the second week of May, the village of Phorste had had no significant rain for over 2 weeks. The results of our ERT survey show that during the dry season there is shallow water flow in the lower portion of the village which consists almost entirely of glacial till to depths below 100 meters. The results were confirmed by the local community who stated that these lower fields flood badly during the wet season and were not good for growing anything other than grass. Our data also showed ground water flow, ranging down to >90 meters depth, along the eastern margin of the village. Most of the village is entirely underlain by glacial till, except along the north-eastern side of the village where the till intersects the mountain slope, and along the eastern edge of the village which is bordered by a large dyke. It is along this eastern dyke that the groundwater flows. At our second community meeting we were told a story from one of the older community members about an old well, in the same location we see groundwater, that was buried in after a yak fell into it and died. This even happened around 70 years ago. The village are now looking into funding to dig or drill a new well in this location.

Two of our longest lines (84 nodes each) at the upper portion of the village. Note the porters taking a break in the background. The porters turned out to be a huge help setting up and breaking down the lines.
Looking towards the northwest. Setting up a long line. From this photo you can see the slope of the land and village.

Five of our lines, with the lowest altitude line at the top and the highest altitude like at the bottom. Note that one line has been flipped so that all of the lines show the same SE (left)-NW (right) orientation.

These lines have not been calibrated to the same colour scale, however, it is possible to see both shallow and deeper water in the lower two lines it is possible to see the bedrock, whereas the upper two lines are all glacial till.

We ran two community meetings. The first meeting, on May 13, was attended by over 30 members of the community, including the village governance committee (they oversee the water project), the women’s committee, and most of the key leaders in the community. The second
meeting, on May 20, was mainly attended by the governance committee. It was during the first meeting that we were made aware that Phortse had just finished their water project and had built both their water filtration and storage systems. Apparently, they were so stressed about their lack of water they decided to proceed without our input, which was a shock for us. However, there were even more keen on our project now because their storage tanks were already dry, and despite the fact that each home now has running water, all of the water samples we tested had fecal contamination (which shows that either their filter is not working, or there are holes in the pipes). To be positive, this has focused the community on their water needs even more, they had a thorough understanding of what is/could be wrong and asked excellent questions. We spent many hours discussing options. In addition, we were joined most days by members of the committee who would ask questions and enter problem solving dialogue.

The May 20th community meeting. University IRB did not permit us to take the names of the participants and does not want us to identify participants, however, we have the names and contact details of the community leaders.

At the May 20th meeting, PI Nicholson is explaining the preliminary results of the ERT survey to the community.

During our time in Phortse our human dimensions team interviewed members of the general community and key informants (community leaders). A total of 5 key informant interviews were conducted, including the local winner of the national election who is now the leader of the entire
region, and 10 interviews with regular people (mostly local farmers). Additional key informant interviews were conducted in Lukla and Namche Bazaar. The interviews are still being transcribed but my main observations are that people are now even more aware of the water problems than they were a few years ago, that the community leaders are determined to find solutions, and that they desperately need our data. It was during these interviews that we were asked repeatedly to test the local bottled water for fecal contamination. The bottled water is marketed towards tourists as they believe it will be safe to drink, however, the community leaders suspected there might be problems. We tested 11 locally produced bottle waters and 10 had fecal contamination.

The results of 100ml of tap water from the new Phorste water treatment system passed through a filter and tested for fecal contamination. The pink/purple dots are total coliform colonies and the blue/teal dots are ecoli colonies.

Two members of our team, who were entirely funded through Ball State University, spent their time in the region surveying tourists about environmental issues. Tourists for an “itinerant” population in the SNP making them a difficult demographic to influence. Over 350 tourists were surveyed. The data is being reduced now and should be ready to share with the communities by the end of 2022.

During our time in Phorste we installed an Aquatroll datalogger. Data will be downloaded four times over the year by two of the Nepali students who came with us into the field. Finally, work has begun, again, on a new website to make the data public. We will also be sending our data and report directly to the community and in May 2023 we will be making a presentation to the National Parks main office.
Dr Han testing the flow rate of the stream below Phorste. This is where we installed a datalogger. This is the pre-monsoon dry season. We hope to collect data throughout the year.

**Interpretation of Data**

Please note that we are still working on our data. All results are preliminary.
- 10 out of 11 bottled water samples contained fecal contamination (between 0 and 300 CFU)
- 10 out of 10 household water samples tested had fecal contamination (between 1 and 200 CFU)
- Most of the village of Phorste is underlain by significant depths of glacial till. The only solid rock occurs in the northern and easter edges of the village. One of the new water storage tanks and the water filtration system is situated on shallow till (<5m) above bedrock, the other is situated on glacial till with an unknown depth to bedrock.
- Geological observation suggests there is a fault running through the center of the village. This hypothesis has not been tested but will be investigated in 2023.
- Ground water was found running along the eastern margin of the village.

**Summarize Field Studies**

- All student participants were involved in the ERT survey and learned how to use the equipment.
- All student participants were involved in the water sampling and analyses.
- All student participants were involved in the community meetings.
- All students are currently involved in reducing data and preparing summaries for the community and for conference presentations.

**Human Element**

The project utilizes the MoU between BSU and Kathmandu University. Our team is a mixture of social and physical scientists. Drs. Nicholson, Neumann, Han and Sharma are focused on the physical sciences, including geological mapping, the ERT survey and water quality. Dr. Gruver will focus on the social side of the project; hosting community meetings and working with
community members to ensure the success and longevity of the research. Additionally, Drs. Nishikawa and Hall are joining the project. They will work with tourists to identify key factors that might help shift a portion of responsibility for environmental degradation away from the community and onto the tourists.

Our students will be spread across disciplines. The Nepali students will primarily work on the ERT survey and geological mapping. Ms Achyara will work on water quality and the impact of climate change on drinking water resources. Ms Hayes will be working on conflict resolution and community resilience in the fact of environmental degradation with the aim to strengthen sustainability. Ms Cobb will be working on the ERT survey and liaising with the community to ensure data is available for their use.

Project sustainability

This project is very community driven. The local communities identified and understand the need for long-term access to potable water. In order to realise this goal, the communities have/are raising funds to build their own water treatment and storage facilities. Phorste have, as of April 2022, finished building their water treatment facility and three storage tanks. They had just finished construction on the last tanks a couple of days before we arrived. Unfortunately, one of the tanks is seated on deep glacial till and all tanks had already run dry as of May 2022. As a result of our work the village has two ideas they are planning to try to raise funds for: firstly, they want to build a forth storage tank on safer ground, and secondly they will seek funding to build a deep well in the northeast corner of the village. This will necessitate the help of engineers as the well will run through at least 40m of glacial till before hitting bedrock. In addition, our sampling of household water shows that despite filtering the water most households have contaminated water. Each household and lodge pays a yearly fee for the water. The village is still working on the amount each household should pay, but at the moment it is around $5 USD for a family of four. Hence, the village have the funds to fix the lines and they realise that they need to replace most of the distribution lines although it is unlikely to happen until next year (this is a complicated local problem which I will not go into detail about here). The village is very pleased with our results and are waiting for a more formal presentation of our data, which we hope to do via ZOOM in October. Our data has helped Phorste realise that they have a good water source at depth that would help alleviate their water vulnerability.

The village of Lobuche is still raising funds, but hope to start work on their system in the next two years. Khumjung village is now also starting to raise funds. All of these villages are utilizing the sustainability model used by the village of Lukla. Lukla built their facility 6 years ago and are successfully maintaining it. This same model has been used, successfully, in two additional lower altitude villages. The NGO Action for Nepal is helping the villages successfully implement the system.

Finally, bottled water. Many villages have small water bottling facilities, usually run by a local family. These facilities claim to filter the water but most of them refused us access to these facilities. We tested 11 bottles of water, each purchased from a local shop, and each from a different bottling facility. 10 out of 11 of the bottles had fecal contamination, in some cases worse that the local water we tested from the source. The local governing committee and the villages all want to have our data so that they can force these facilities to improve the water
quality. We will present this data to them in August or September, once we also have the chemical analyses completed, via a formal ZOOM meeting.

**Education**

KU is actively involved in the project. The project will provide research opportunities for two undergraduate and two graduate students. None of these students are familiar with ERT. In addition, we have a Nepali PhD student, based at BSU, working on the project. Professor Sharma and his Aquatic Ecology laboratory are actively involved in the project and some of the laboratory analyses will take place at KU. In addition, they were responsible for securing the research permits for 2022.

Local residents, particularly the community committees and local school children will be given the opportunity to participate in the research. We hope to visit at least one local school and test their water with the children.

**Problems or Challenges Encountered**

Due to the COVID-19 crisis, the planned field visits for both 2020 and 2021 were cancelled. During this time we identified several minor problems with the ERT which we were able to fix. The other problem that we have faced is that the students employed to complete an accessibly webpage have either quit or graduated. As a result our webpage is not complete. Ideally, we will have this problem corrected by the end of the summer of 2022.

Two “one year” no cost extension were granted to this project. With the recession of the pandemic, the team will complete the first part of the proposed project in May 2022. We are currently debating the benefits of completing the project in October 2022 or May 2023.

In the field we encountered many problems, which is to be expected in remote high altitude communities.

- Firstly, we did not realise that the national election was being held while we were there. When we arrived in Nepal it was suggested to us that we work in a completely different region due to the elections because everyone would be too busy with the election, but in the end we decided to stick to our original plan. This worked in our favor as normally all of younger men in the village would be trekking, including the village leaders, but they were all home for the election. In fact, the election ended up being very positive for our community outreach for a variety of reasons, not the least of which is that we lent our generator to the village to host an election party (the village had no power as there was no rain, and we had the only generator in the village).
Mechanical problems. The generator proved to be a major problem. Our first generator broke on day 2. We were lucky as there was someone in the next village (4 hours walk) who could possibly fix it. He came, found the problem, walked back to his village, took a part out of his generator and lent it to us to fix ours. Our generator then worked for one more day before breaking again. This time our porters went and got the other generator, only to discover that the replacement part had broken and we now had two broken generators. We then arranged for one of our students relatives to buy a new generator in Kathmandu and get it to the airport. This took two more days to arrive. In the meantime we did one run on the back-up batteries, but with no means to recharge the batteries we could only do one run. The new generator arrived, work fine for the rest of the trip, but then the switchbox stopped working.

Photograph showing two broken generators with an ERT line set up in the background. On this particular day we set up the same 84 node line 3 times with no results.
Potatoes and Yaks! The village of Phortse is the main potato growing village in the region. Potatoes give poor families and women an income. Because 2022 was warm and wet in April, the potato crop was planted early and not everyone was happy to have us string lines through their potato fields. This caused delays in laying lines as we had to talk to the owner of each potato field. Not all field owners could be contacted and some, particularly field owners who did not live in Phorste, gave us permission. As a result, we had to adjust, relocate and/or shorten lines on several occasions. Yaks also posed a problem in that we were afraid that such large animals would break the cables. As a result we tried to avoid major trails likely to have Yak traffic.

Photographs showing one of our long lines (84 nodes) going around a recently planted potato field, and a train of Yaks passing along one of the major trails, which we chose to avoid.

The water project was already finished! Unbeknownst to our group, the village had proceeded with building their water filtration and storage system. At first we questioned why we had bothered to turn up! But then, after taking with the local water committee, we discovered that the project was fraught with problems and they needed our data even more than ever. The village is piping water from two springs, but there is still not enough water. The “new” water is more contaminated than their old source and there appear to be holes in their distribution lines as all of the tap water we tested contained fecal contamination.
The first photo shows the new water storage facility which is built entirely on glacial till. The second photo shows the same storage tank is nearly empty.

- A problem, for which I am working on a solution, is that the university would not allow me to pay the Nepali students the salary moneys in the budget. I am trying to figure out how to pay them retroactively for “services” on the project. For example, two of the students are going into the field to download data from the datalogger and I hope to hire them as contractors. I wish I had known this prior to travel. If this works, then in 2023, I am going to hire all of the Nepali students as contractors so that I can avoid this problem.

- Finally, over ambitious ideas! The PI had over ambitious ideas regarding what the group could accomplish at 4000m elevation in 2 weeks. I had thought we could do 2 ERT lines per day, but even with the porters helping to lay cables and stakes, it was exhausting. Due to mechanical problems, most days we managed one line, but twice we attempted two lines in one day and once we laid three lines (but the generator broke each time). I will openly admit that this was a mistake. On these days the entire group ended up overly tired. Especially as we had interviews and water samples to analyse most evenings. Next year I will change how we manage the ERT lines so that we can, hopefully, get more done without exhausting everyone. Also, it was not possible to complete the geologic mapping in 2022. Basically, we tried to do too many things in too short a timeframe.

**Evaluation of project schedule**

In 2022 we were working in the village of Phorste. We also visited the village of Lobuche.

1. Delineate community aquifers,— **75% completion.** We have collected the data and are working on it now.
2. Quantify seasonal recharge and discharge, – **10%** In 2021 a group from Tribhuvan University working with ICIMOD and some foreign collaborators installed a weather station in Phorste. We are working to get access to this data. At the moment, they have agreed to give us the data with a one year delay (i.e. they will currently give us the 2021 data).

3. Assess location of locally built filtration system, – **90% completion.** We have assessed the locations, including the depths to bedrock, and we will give feedback to the village within the next six week. However, we need to assess the possible fault location in more detail before this is 100% complete.

4. Map the geology of the basins, including structural geology, rock types and basin fill, – **50%** We have mapped the glacial till and we know the basic geology, but we have not mapped the structural geology or the intrusions in detail. We plan to do this better in 2023.

5. To help develop long term strategies for water management and help mitigate the long term effects of climate change and minimize potential earthquake risk. – **50% completion** This is ongoing. We started working with the community on ideas and problem solving. We will be giving a large presentation of all of our results – we will probably give two presentations, one via ZOOM in late 2022 and one in person in 2023. The government, national parks office and the community will all be present.

6. Sustainability. – **70% completion** Phortse are working on their distribution and charging structure at the moment. Their current water filtration and storage system is sustainable, however, we have shown that there are problems with the current system that must be addressed. In addition, they are still running short of water, even in 2022 which was a wet year, and they would like us to help them apply for funding to put in a new well (to the groundwater source we found).

**Access to Data**
We have already shared our very preliminary findings with the village of Phorste and with the NGO Action for Nepal. We plan to send a more formal report by the end of August, 2022, and we are working on our website. We will also make our data public once we have published our preliminary findings.
Below are the options you will be asked to consider on your final report:
Current Status and Revised Timeline
This timeline has been adjusted due to the travel ban caused by the C-19 pandemic. We have been granted two 1 year no-cost extensions, hence our new timeline extends to Year 4. We have completed the field portion of the project in Phorste in 2022 and will repeat the project in Lobuche in 2023. Please note that the timeline table includes sharing of data and the continuation of graduate students working on the data.

Task 1: Delineate community aquifers. – Phorste: May 2022 and Lobuche: May 2023 – All data reduction should be completed within 6 months.

Task 2: Quantify seasonal recharge and discharge, Phorste: May 2022, currently we only have data for 2021, but we should start getting data from our datalogger soon and hope to get precipitation data by the end of the year. Lobuche: May 2023, again we hope to access data from an newly installed weather station.

Task 3: Assess location of locally built filtration system, Phorste: May 2022, we have already given some feedback and will meet with the community again in 2022 and 2023. Lobuche: May 2023.

Task 4: Map the geology of the basins, including structural geology, rock types and basin fill, This is partially complete and we hope to finish this task for both Phorste and Lobuche in 2023.

Task 5: To help develop long term strategies for water management and help mitigate the long term effects of climate change and minimize potential earthquake risk. We started working with Phorste in 2022 and hope to have valuable feedback and data for them within the next few months. Lobuche: May 2023. Hopefully, the lessons learned in Phorste can be applied to other villages in the region too.


Project Timeline:
Grey: Phorste
Blue: Lobuche

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