# Web-Based Relational Spatiotemporal Geodatabase of Glaciers in California

by

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To my wife, who never lost faith in me. Without her love, patience, and support I would not be here.

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# List of Abbreviations

| | |
|---|---|
| AWS | Amazon Web Services |
| CDP | Census-designated place |
| ERD | Entity Relationship Diagram |
| GAW | Glaciers of the American West |
| GIS | Geographic information system |
| GISci | Geographic information science |
| GLIMS | Global Land Ice Measurements from Space |
| IAD | A web-based, relational database for studying glaciers in the Italian Alps |
| NPS | National Park Service |
| NSIDC | National Snow and Ice Data Center |
| RDS | Relational Database Service |
| RGI | Randolph Glacier Inventory |
| SQL | Structured Query Language |
| SSI | Spatial Sciences Institute |
| USC | University of Southern California |
| USGS | United States Geological Survey |
| WGMS | World Glacier Monitoring Service |

## Abstract

Glaciers are an important indicator of global and local climate change, an important factor in regional environmental health, and a possible natural hazard. The importance of glaciers has led to the creation of many glacial inventories ranging in scale. The datasets from these glacial inventories are often outdated or incomplete, especially for those in California. Additionally, none of the glacier inventories track change in the glaciers over time, but rather they are limited to the data at a single point in time in California. The objective of this project was to create a web-based relational geodatabase and web map to track spatiotemporal information of glaciers in California. The geodatabase was designed with three user groups in mind: geologists and glaciologists, policy makers, and the general public. The geodatabase was also designed to meet several goals. The first was to archive and store the large amounts of glacial data collected by other sources, add temporal attribute onto current glacial data, and plan for new types of data. This was done by developing the database in such a way that it meets current requirements and standards of existing global glacial databases. Additionally, another goal was to create a web map that allowed the data to be easily accessible and useful for various users with different goals. A web map was constructed to display the data within the geodatabase and allow the user-groups to interact with and download the data. The results of this project including the geodatabase, data, methods, images and documentation are published at mapping.cool/california-glaciers and on GitHub, along with the web map for public use. This geodatabase and web map can be used for different applications, ranging from the simple uses like as monitoring glaciers to detect change, to more advanced use of the data such as hazard detection and assessment.

# Chapter 1 Introduction

Glaciers are formed from snow that is compressed over many years, into thickened ice masses. Glaciers, unlike stagnant ice masses, flow like extremely slow-moving rivers. Glaciers usually lie within mountain ranges, make up nearly 10 percent of the worlds land area, and store about 75 percent of the world's fresh water (NSIDC 2019). Since the early twentieth century, glaciers across the globe have been receding at remarkable rates (NSIDC 2019). Glaciers are partly of concern because provide a myriad of benefits to us, the natural environment, and other species. Further, they can pose a hazard to human populations. Glacial monitoring is beneficial for the economy, the environment, and human health and welfare. Thus, glacial monitoring is a priority. Given this, the goal for this project was to build a web-based relational spatiotemporal geodatabase for studying glaciers. The geodatabase can be used as a framework for studying and analyzing changes to glaciers over time. Additionally, the glacial database is built in such a way that it can be utilized by multiple types of users. Ideally the database will help monitor changes to glaciers and assist scientists with more advanced analyses like hazard detection and assessment. This type of relational spatiotemporal geodatabase can facilitate the monitoring, study, and analysis of glacial change, and ultimately facilitate our ability to protect the environment, better predict and prevent hazards, as well as navigate complex economic and geopolitical issues that can stem from glacial deterioration.

Glaciers are an integral part of our environment that can, in specific instances, pose hazards to humans and other species. For example, glacial retreat and growth impacts many different ecosystems since the ice serves as a reservoir of fresh water and provides habitats for many species (National Park Service 2017). Additionally, glaciers pose natural hazards, like when a glacier advances several miles in only a few months, an effect known as surging.

Flooding can also occur from the bursting of ice in dammed lakes. Glacial monitoring can help track the changes in glaciers to better predict potential hazards. Glaciers also play an important role in global economy, and glacial monitoring can help determine the commercial value in glaciers for power generation, tourism, as well as the export of glacial ice.

Aside from the natural benefits and hazards of glaciers there are also geopolitical reasons to monitor the change in glaciers. An example of this can be seen in Italy where their northern land border is melting. The northern border passes through high alpine terrain including rock, ice, and seasonal snow. Since 1850, Italy's glaciers have shrunk by approximately fifty percent. As the ice continues to shrink, the watershed between Italy and Austria has shifted. In some areas along the border, the watershed shifted by up to 100 meters. At present, Italy and Austria agreed upon a moveable border on their ice frontiers that fluctuates depending on the location of the watershed and how the ice melts (O'Sullivan 2017). A spatiotemporal geodatabase that looks at the changes in glaciers over time could help these two countries, as well as other territories with similar land-border issues, determine new border lines based on the analysis of the information collected regarding specific glaciers.

Changes in glaciers can aid in monitoring global climate change and can be an indicator of changes in regional and global climate (National Park Service 2017). Basagic (2011) observed that since 1911, fourteen glaciers in the Sierra Nevada Mountains of California decreased in area on average by 55%. The significant degradation of those fourteen glaciers, along with the fact that the last comprehensive inventory of glaciers in the area was done in 2006, demonstrates the need to consistently keep track of these glaciers over time (Basagic 2011).

## 1.1. Motivation

The growing need for improved glacial monitoring and a modernized spatiotemporal geodatabase for glaciers stems from the fact that similar databases are outdated or contain limited datasets. By integrating the existing data from current glacial databases together and allowing for the incorporation of new data types into the modernized spatiotemporal database, the new database would be far more comprehensive than the other databases themselves. Additionally, this new database would have a chronological record of data for the glaciers which would provide a better picture of the change in the glacier over time rather than just a snapshot, which is what is the current glacial inventories provide. Lastly, the database would improve upon the existing databases in that it would be formatted in such a way that it would be easy to access by various entities and researchers and could serve as a centralized database for glacial monitoring in California.

Currently, the largest glacial database is Global Land Ice Measurements from Space (GLIMS). The National Snow and Ice Data Center (NSIDC) develops tools, including GLIMS, to aid in glacier mapping and transfers the analysis results of measurements to the NSIDC. Over sixty institutions from around the world participate with GLIMS, while most of the coordination, technical development, and data management occurring at the NSIDC in Boulder, Colorado. According to GLIMS, their primary method of monitoring the world's glaciers is using optical satellite imagery (Global Land Ice Measurements 2018).

GLIMS database and web map are similar to this project, but one of problems with the GLIMS data for California is that many of the fields used to describe and monitor glaciers have NULL values. Specifically, fields such as Glacial Form, Frontal Characteristics, Longitudinal Profile, and Source Nourishment all have NULL values. This is due to the analyst at the time of input either not being able to determine the value or not taking the time to determine the value of the attribute. Additionally, the data from GLIMS and other glacial inventories provide only a snapshot in time and lack the ability to view a glacier change over time. Having more temporal data would allow for This project built a more complete geodatabase of glaciers in California, while also providing a temporal dimension to the data.

Another example of an existing glacial inventory is the Randolph Glacier Inventory (RGI), which was created in response to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC AR5). The inventory prioritized completeness of coverage, but the attributes were limited. Satellite imagery from 1999 to 2010 was the basis of most of the outlines (Pfeffer et al. 2014). The main contributors of uncertainty are debris and seasonal snow that cover the glaciers, but there does not appear to be a normal distribution of these errors (Pfeffer et al. 2014). Currently, many glaciers only have information on area and location, and still need other data like topography and hypsography. One of the disadvantages of this inventory is that it was created in a short period of time with limited resources (Pfeffer et al. 2014). Additionally, the glaciers in the inventory are only from a snapshot in time and do not contain a temporal element (Dempsey 2014). Once again, the present project aims to create a geodatabase of California's glaciers that will provide a temporal element to the data collected as well as provide a more comprehensive inventory of the glaciers than the existing databases.

Despite the work done by others collecting the current glacier inventory data, more data can be gathered at a greater spatial and temporal resolutions than what was previously collected. In the past, the advantage to using satellite data was that it was much more convenient to inventory glaciers in large remote areas (Aninya et al. 1996); however, modern technological advancements such as newer satellites, UAVs and LiDAR have allowed for greater resolutions.

For example, in the Trinity Alps of California, there are over thirty-five perennial snow fields and several small glaciers mapped by the USGS, though it seems many of the bodies that USGS maps do not remain at the end of the second half of the year, and these glaciers are not currently mapped by either GLIMS or the RGI (Basagic 2011). This database integrates existing inventories, as well as aims to allow for the incorporation of new data collected with more advanced technology and improved resolutions.

## 1.2. Study Area

This project creates a geodatabase and web map for glaciers within the state of California. In California there are four glacial regions: Sierra Nevada, Trinity Alps, Mount Lassen and Mount Shasta. Mount Shasta and Mount Lassen are both within the Cascade Range (Figure 1). In California there are over 1700 snow or ice bodies which cover more than 46km$^2$ of California (Basagic 2011). 20 of them are named, 13 of which are in Sierra Nevada while the other seven are around Mount Shasta. The Sierra Nevada Mountain Range is approximately 640 miles long and located along California's eastern border. The USGS mapped more than 1600 glaciers and perennial icefields in the Sierra Nevada Mountains (USGS 2018). The Trinity Alps are located to the west of the Cascade Range and they contain thirty-nine small glaciers, as well as perennial snow fields with an area of approximately 1.9km$^2$. None of the glaciers or snow fields have USGS names (USGS 2018). Mount Shasta is a stratovolcano located in northern California in the Cascade Range (Basagic 2018). There are seven glaciers around the peak of Mount Shasta including Whitney, Bolam, Hotlum, Konwakiton, Watkins, Mud Creek, and Wintun. The total area of these seven glaciers is approximately 4.9km$^2$, the largest of which resides on the north face of Mount Shasta. The last glacial region is Mount Lassen which contains nineteen small snow and ice bodies that have an area of less than 0.3km$^2$, none of which have names (USGS 2018).

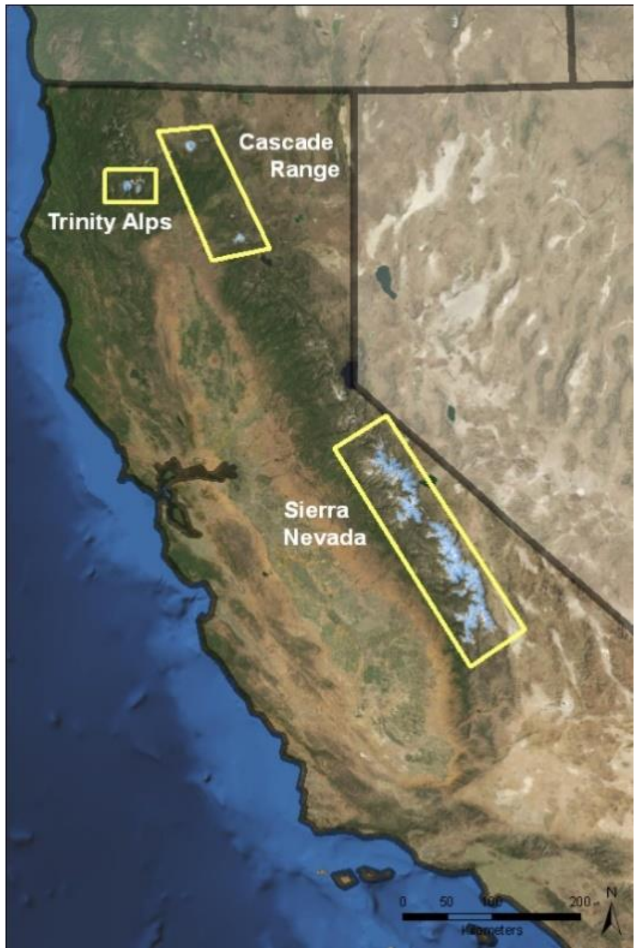


Figure 1 Glacial Regions of California. Source: Basagic 2011

Both the Sierra Nevada and Mount Shasta glacial regions have multiple cities very close to the glaciers, such as Mammoth Lakes in the Sierra Nevada Mountain Range and the town of Mount Shasta in the Cascades. Changes to the local glaciers would affect these cities and many others. Additionally, many of the glaciers in Sierra Nevada belong to the same watershed as Owens River, Owens Lake and Mono Lake, all of which are used to provide water to the Owens Valley Aqueduct. The Owens Valley Aqueduct provides large amounts of water to Los Angeles.

Creating a database with an updated inventory of the glaciers in California would aid in glacial studies and increase our understanding of the changes occurring to the glaciers. Tracking and mapping glacial changes is becoming more important than ever and will greatly improve our understanding of the role of glaciers have in the economy, the environment, and in the welfare of countless species. The present project provides one step towards improving glacial monitoring and highlighting the need for spatial-temporal glacier monitoring globally.

## 1.3. Research Objectives

The present study incorporates three main criteria to shape the design and implementation of this web-based geodatabase for California glaciers. The first goal is to develop the database in such a way that it can catalog data sources for glacial data that meets current requirements and standards of existing global glacial databases. The second goal is to archive and store the large amounts of glacial data collected by USGS, Global Land Ice Measurements from Space (GLIMS), Randolph Glacier Inventory (RGI), and other sources, as well as to plan for new data types in addition to the data types and formats currently being used. The archived data will include information of California glaciers from various snapshots in time and provide a chronological record of data from each glacier. The third and final goal for the design of the database is to make the data easily accessible through a web map and Githuband for various users. These goals will help make the spatiotemporal geodatabase for California glaciers comprehensive, easy to access and use, and help to highlight the changes to the glaciers over time.

## 1.4. Thesis Organization

This thesis contains four additional chapters. Chapter 2 examines related works and the datasets used for this project. It looks at the intended user groups and their various use cases. It also discusses spatiotemporal database design and evaluation, as well describes GIS and how it is used to visualize glacial and ice mass data. Chapter 2 also examines the various glacial and hydrological databases and datasets which are used in the present project. Chapter 3 discusses the methods used to design and create the project geodatabase and web map. Chapter 3 is broken down into five subsections: Design Principles; Design and Implementation of Geodatabase; Map and Feature Service Creation, Web Mapping Application Creation, and lastly a Summary of Database Design Steps Completed. The subsections explain the work and through process used to complete this project. Chapter 4 examines and discusses the success and limitations of the final geodatabase design, as well as the final web map. The last chapter, Chapter 5, looks at suggestions from the survey that can be implemented in the future; as well as future directions this project can go. The final chapter also discusses lessons learned throughout the process of this project.

# Chapter 2 Related Work & Datasets

This chapter provides a framework to understand how the spatial-temporal database for this thesis project was designed, organized, and implement; as well as introduce each dataset and explain why each dataset was chosen for inclusion in the project. This chapter is broken up into four sections: Intended User Groups and Use Case, Spatiotemporal Database Design, Glacier Databases and Inventories, and Background on the Glacial Datasets in the Geodatabase. The first discusses the various user groups and how they may use the database. The second section is a brief overview of the texts that guided the spatiotemporal design of this project's geodatabase. That is followed by an overview of existing glacial geodatabases focusing specifically on GLIMS and a web-based, relational database of glaciers in the Italian Alps. These were selected because of their well-developed status and similar design goals to those of this project. Finally, there is a discussion of the datasets included in the project, why they were included, and what they lack.

## 2.1. Intended User Groups and Use Case

In order to ensure that the design of this project's geodatabase and web map proved useful, three user groups were identified: geologists/glaciologists, policy makers, and the general public. Each user group has a different level of expertise in GIS; for example, geologists and glaciologists would be considered expert to intermediate while policy makers and the general public would be considered novice GIS users.

### *2.1.1. Geologists / Glaciologists*

The primary users of this geodatabase will be glacial researchers. These users will likely have proficiency in GIS and an in-depth knowledge about glaciers and ice masses. Glacial researchers can use this geodatabase in conjunction with their own data to perform complex analysis such as hazard detections and assessments. Additionally, glacial researchers can use data obtained from the geodatabase to assist in conduct various types of spatial analysis, such as detecting change in glacier system and assessing the impact of said change or examining an abrupt change in an ice shelf. For the present project, external attributes such as the source of nourishment for a glacier were excluded because glacial researchers can join their data of external attributes to the glaciers, rather than this project trying to include every external attribute possible. The present project also excluded all data outside of the spatial-temporal location of glaciers because the amount and types of analysis that glacial researchers perform is so varied that the researchers can integrate their own data for their specific project with the glacial data this project provides. This particular user group can use the geodatabase in both its file form or as a web map.

#### *2.1.2. Policy Makers*

While some policy makers may harbor basic proficiency in GIS and glacial research, it is unlikely that most have a strong foundation. Policy makers can use the web map to see where glaciers are, both within and in relation to, their jurisdiction. Being able to observe the glaciers or any glacial change relevant to their jurisdiction allows policy makers to create policies that will help protect their constituents as well as the natural environment. Because of the potential limited knowledge of GIS among policy makers, both the geodatabase and web map are designed to be functional for both the novice and the expert.

#### *2.1.3. General Public*

The general public user group is made up of users who are citizen scientists as well as individuals who just want to know more about glaciers. The use case for this type of user will likely be motivated by curiosity and/or concern about changes in glaciers. The general public will have the simplest GIS needs of the geodatabase; for example, users in this group will likely be concerned with glaciers in the nearby vicinity. Furthermore, it is less likely that these users have be a specific research goal, in contrast to the research of the geologists and glaciologists user group. As such, the data included for the general public user group will be more general in nature, such as including a base map with common reference locations like nearby cities.

## 2.2. Spatiotemporal Database Design

The spatial-temporal database design research included reviewing textbooks such as Yeung and Hall's Spatial Database Systems (2007), which provides a comprehensive look at the methods, implementation, and management of spatial database systems. It also involved examining articles by Microsoft (2019) and ESRI (2019) on database design basics. The aforementioned texts discuss important aspects of design such as development, management, and maintenance, but they did not provide information on how to capture the temporal aspect of data. Wachowicz (2014)'s Object-oriented design for temporal GIS, on the other hand, is a textbook entirely devoted to the subject of temporal data. Specifically, the textbook discusses object-oriented analysis and design methods, how object-oriented design can be used to model spatial-temporal data, and it outlines methods to develop and maintain this data within a GIS. These texts on spatial-temporal database creation acted as a guide for the development and design of the geodatabase.

## 2.3. Glacier Databases and Inventories

This section examines other glacial inventories, the advantages and disadvantages of each, and how they contribute to the thesis goals. GLIMS and the design from the article "A web-based, relational database for studying glaciers in the Italian Alps" (referred to hereafter as IAD) are discussed in detail, as they form the foundation of the geodatabase and web-viewer design. Research was conducted through online scholarly databases and internet web searches on other glacial and hydrology databases and datasets to help provide the necessary design consensus on what data was incorporated into the final thesis project. Additionally, the research highlighted the fact that the current datasets are missing elements that the final geodatabase included to make it more comprehensive and user-friendly.

### *2.3.1. GLIMS*

GLIMS is an example of a “complete” inventory of glaciers. This thesis builds upon this type of inventory but provides greater temporal resolution. Currently the largest glacial database, GLIMS develops tools to aid in glacier mapping and transfers the analysis results of measurements to the National Snow and Ice Data Center (NSIDC). Over 60 institutions from around the world are involved with GLIMS, while most of the coordination, technical development, and data management are done at the NSIDC in Boulder, Colorado. According to GLIMS, their primary method of monitoring the world’s glaciers is using optical satellite imagery (Global Land Ice Measurements, 2018).

GLIMS employs two main tables to store data about the glaciers, Glacier_Static and Glacier_Dynaimic. The former stores information about the glacier that does not change, such as the glacier name, while the latter stores the measured attributes and the glacial outline. In addition to the two main tables there are additional tables that hold related information such as the participants in the GLIMS project. One problem with the GLIMS data of California is that many of the fields used to describe and measure the glaciers have NULL values. These fields include Glacial Form, Frontal Characteristics, Longitudinal Profile, and Source Nourishment.

Definitions of these attributes, along with the full list of attributes in GLIMS, can be found in Appendix B. One thing that GLIMS does that this project emulates is their viewer, as it is extremely functional and allows the user to quickly find a glacier, view it, and download the data.

*2.3.2. IAD*

In the article, "A web-based, relational database for studying glaciers in the Italian Alps", the authors outline their method for creating a geodatabase to monitor and catalogue the glaciers of the Italian Alps (Nigrelli et al 2013). This database's design compares similarly to how GLIMS is designed which is pointed out in the article. The authors discussed their methods of how they built a relational database with a web-interface. They had 59 different tables with the main schema at the center ("glaciers") after which they partitioned the tables into six different groups: Location, Morphologic/Metric Info, Orographic Info, Attachments, Campaigns & Mass Balances, and Users. These groups were further partitioned into subsections. They point out that the purpose of the glacier table is to provide basic information about the glacier, but more importantly, to link to additional information held in the other table. The authors go onto describe the sub tables of each group and what their purpose is and why they included them. This helped the author decide which tables to include in their geodatabase. After a discussion of the design and structure of the database, they describe the web-interface and how it is used, accessed, and searched. This is article provides insight on the integration of new types of data and how to associate it with the glacial data, and how to collect and disseminate the data that has been amassed (Nigrelli et al 2013). This geodatabase is an example of a model built to integrate new data, maps, and imagery used to guide the design of the geodatabase for this thesis project. Unfortunately, the actual database is no longer available for viewing as the URL provided does not go anywhere, and the author had to go by methods discussed in the article to follow their process and incorporate it into this project.

## 2.4. Background on the Glacial Datasets in the Geodatabase

There are currently several global, national, and multi-state databases that exist which contain datasets for California-specific glaciers that the author incorporated and expanded upon in this thesis project. There are five databases included in this study and of those five only one has glacial data stored at more than one point in time, and none of them do for California. This is what the author believes the main difference between this thesis and other similar works is. Three of these are global: GLIMS, RGI, and WGI, one is national: USGS NHD, and one is multi-state: Glaciers of the American West. This section discusses each of these datasets, what they add to the project, and what they may be missing.

### *2.4.1. GLIMS*

The most formidable of the current global glacial databases is GLIMS. Hence, GLIMS is a seminal database for this thesis. GLIMS is not only a geodatabase of glaciers but includes the GLIMS Glacier Viewer which is an interactive map that allows the user to view the data. The GLIMS Glacier Viewer contains layers that are viewable and searchable, and outlines can be downloaded in a variety of file types. The GLIMS database is currently the foremost web viewer and interactive map containing glacial data.

GLIMS has 960 glacial features in California, none of which have multi-temporal coverage. The data within in the database are vector shapefiles containing both points and polygons. The data features are from 2006 analysis that used imagery from 1953 to 1984. There are 37 attributes for each feature within this geodatabase, but only eight attributes are measured attributes of a glacier. These include DB_AREA, AREA, WIDTH, LENGTH, PRIMECLASS, MIN_ELEV, MEAN_ELEV, and MAX_ELEV; to see descriptions of these attributes see Appendix A List of Attributes from GLIMS. Of the eight measured attributes, only three have a non-zero or NULL values. While GLIMS is a strong example for how to build and allow for viewing of glacial data, its own data for California is lacking in terms of temporal coverage and completeness of attributes.

*2.4.2. RGI*

Another example of a current global database is the Randolph Glacier Inventory (RGI), which is a collection of digital outlines of glaciers and is meant to be globally complete. Approximately 198,000 glaciers in the inventory were derived from satellite imagery from 1999-2010. Version 1.0 was released on February 22, 2012, and the current version (6.0) was released July 28, 2017. Updates to RGI are now made in parallel with GLIMS during a transition period, after which RGI will evolve into a subset of GLIMS offering complete one-time coverage, version control, and a standard set of attributes.

Because RGI is now being developed in parallel with GLIMS it contains the same number of features as GLIMS (960). Though RGI contains additional measured attributes that are not a part of GLIMS, such as Slope, Aspect, Form, Surging, and Linkages. A full list of attributes and descriptions for RGI data can be found in Appendix B List of Attributes from RGI. In addition to having the same number of features as GLIMS, RGI also uses the GLIMS ID number as the unique identifier for each glacier. Like GLIMS, RGI data is a vector shapefile that contains polygons. RGI is a much more attribute complete dataset than GLIMS, but by design lacks temporal data and tracking of glaciers.

*2.4.3. WGI*

The last dataset included in this project is Version 1 of the World Glacier Inventory. The entirety of this data set contains data for over 130,000 glaciers. Most glaciers only have a single entry, including all the glaciers within California, and therefore offer only a snapshot of glaciers during the second half of the 20th century. The data in this data set is primarily based off aerial photographs and maps. Unlike the other data sources for this project, WGI contains vector point rather than polygon outlines of the glaciers. In total, WGI contains 497 features, with updates in 2008 from 1989 WGMS and NSIDC data. This data set contains additional measured attributes not found in the other datasets that are part of this project such as SOURCE_NOURISH and TONGUE_ACTIVIY. SOURCE_NOURISH is a 1-digit code that describes the glaciers source of nourishment such as snow, avalanche, or superimposed ice. TOUNGE_ACTIVITY is a 1-digit code that describes the activity of the tongue of the glacier such as retreating, stationary, advancing, or surging. A full description of the WGI attributes can be found in Appendix C List of Attributes from WGI. Even though this data source has few features within it, it adds to this project because it adds another snapshot in time for the glaciers that it shares with the other data sets. WGI also adds additional measured attributes that are considered and added to the final geodatabase.

*2.4.4. USGS NHD*

In addition to strictly glacial datasets, one hydrology dataset and the associated glacial/ice mass data was included. The USGS includes the National Hydrography Dataset (NHD), which is a geospatial dataset of the surface water of the United States. It models features such as rivers, streams, lakes, and glaciers, and it is currently the most up-to-date hydrography dataset for the

United States. As such, the National Hydrology Dataset is the most complete hydrographic dataset in the United States and contains the most current data on glaciers and other water features in the United States. However, like GLIMS and RGI, the USGS data does not contain a temporal aspect.

The USGS NHD contains 1710 Features that are classified as glaciers or permanent ice masses. This dataset contains features updated from 2002 to 2018. NHD contains information about not only glaciers and ice masses, but also rivers, lakes, streams, etc. Therefore, there are only three measured attributes directly pertaining to the glaciers in this database. A full list of attributes and their descriptions can be found in Appendix D.  So, while this while this data is the most update it holds less measured attributes then any of the other included datasets. Additionally, having a feature count that is nearly double that of GLIMS indicates that many of the features are not glaciers, but rather permanent ice masses.

*2.4.5. Glaciers of the American West*

Glaciers of the American West is a small dataset provided by Portland State University. It contains 95 glacier features within California, none of which have a temporal element. This dataset is based off USGS 1:1000,000 scale maps using features identified as glaciers, which according to the authors may or may not meet the criteria of an active glacier. A full list of attributes and their descriptions can be found in Appendix E List of Attributes from Glaciers of the American West

*2.4.6. Insight from Glacier Studies*

Previous glacier databases and inventories, like those discussed in Chapter 2 which catalogue and inventory glaciers around the world, suggest that completeness of attributes and data relating directly to the glacier features is important and useful to quantify, especially over time. Adding this information into a main glacier database will increase the value of said database to anyone who wants to study changes to glaciers. While data about the glacier itself is important, other glacial databases and inventories suggest that there is little need to include a great deal of information that glaciologists and geologists may obtain or use from other sources. Adding more information than necessary to the database would needlessly increase its size. Therefore, layers such as land use, surface water data, watersheds and drainage basins, principle aquifers, drainage networks, etc. were excluded from this database. Data such as those listed previously can be found and spatially related relatively easily as needed for additional studies.

#### *2.4.7. Insight from Key Glacier Database Models*

There is data from five glacial databases included in this project. Of those five databases, only GLIMS has the ability to store the changes to glaciers overtime, but only has one point in time for the glaciers in California. IAD is another relational database that stored data on glaciers over multiple periods of time. These two databases provided insight on this geodatabase was built.

Both the GLIMS and IAD databases have a schema that is centered around a table(s) that represents the main domain of interest, the glaciers. For GLIMs, this is two tables- glacier_static and glacier_dynamic. The former stores information about the glacier that is unchanging, while the later stores measured attributes of the glacier such as the outline, size, form, and frontal characteristic. In IAD, they use a single table to represent the glaciers. GLIMS and IAD also use additional tables to hold related information. For GLIMS this includes tables of information on the participants in the GLIMS project, as well as information such as the Point_Measurement table which holds physical records of glaciers, such as temperature or debris thickness, but that are not part of what they call an analysis or “snapshot” of the glacier. IAD has a total of 59 tables that contain information related to the glaciers or management of access to the database. The 59 tables are partitioned into six groups. Four of the groups of tables contain additional information related to the glaciers, one contains attachments, and the last manages user access.

After examining the approaches that GLIMS and IAD used in developing their geodatabases, it was determined that the geodatabase would use a similar schema, in which there is a central table(s) that holds information about the glaciers and additional tables that contain related information. Like GLIMS, the author chose a similar structure with a glacier static and a glacier variable table, rather than the more complex structure of IAD with many tables and those tables broken down into groups. One of the reasons for this was because the data came from many sources with varying levels of completeness with a wide variety of attributes, which meant that complexity of linking, filling, and updating those tables would be much more difficult than a unified glacier variable table.

# Chapter 3 Database Design and Implementation

The primary goal for this thesis project was to build a spatial-temporal database of glaciers in California with a web interface. The project had three primary criteria that fell under the main goal. The first criteria was to develop the database in such a way that it can catalog data sources for glacial data that meets current requirements and standards of existing global glacial databases. The second was to archive and store the large volume of glacial data, as well as plan for new data types beyond the data types and formats currently being used. The third objective was to make the data easily accessible through a web map and Github repository. These objectives were accomplished by operationalization of this thesis project, which was done through the creation of the geodatabase and the web interface. The first operationalization, geodatabase creation, accomplished the first two objectives. The web interface, operationalization two, achieved the third objectives. Adapted from existing glacial inventories, the geodatabase was designed to incorporate key attributes and functions while also storing the ways in which the glaciers change over time.1 This chapter covers the design principles that guided the geodatabase and web map creation, explains how the author designed and implemented the geodatabase, and discusses the web map creation.

## 3.1. Design Principles

The geodatabase and web map design were guided by three factors: the needs of the user groups, insights from previous glacier studies, and existing glacial database models and inventories. User groups were discussed in Chapter 2 and the rest of this section will summarize design principles that directed the geodatabase and web map designs based off the research done in Chapter 2 of this thesis. This section reviews the choices made about the essential principles that directed the database design.

*3.1.1. Refinement of Existing Database Models*

GLIMS served as the primary model for the design of the tables, static glacier table (glaciers_static) and entity relationship diagram (ERD) for the geodatabase, but the attributes for glacier variable table (glaciers_variable) came from all five of the databases' glacial inventory sources. Because the completeness of attributes associated with each glacier is extremely important, any measured attribute from each of their data sources was included. Table 1 shows attributes that were included in other glacial inventories that were included in glaciers_variable, and a full list of attributes included can be found in Appendix F glaciers_variable Data Dictionary.

Table 1 Common Attributes in Glacial Inventories

| **glaciers_var** | **GLIMS** | **RGI** | **WGI** | **NHD** | **GAW** |
|---|---|---|---|---|---|
| glacier_id | GLAC_ID | GLIMSId | wgi_gl_id | Permanent Identifier | |
| submission_id | | | | | |
| glac_name | GLAC_NAME | Name | gl_name | GNIS_Name | GLACNAME |
| area | AREA | Area | total_area | | Area |
| perimeter | | | | | PERMIETER |
| min_elev | MIN_ELEV | Zmin | min_elev | | |
| max_elev | MAX_ELEV | Zmax | max_elev | | |
| mean_elev | MEAN_ELEV | Zmed | mean_elev | Elevation | |
| in_basin | | | drain_code | | |
| num_basins | | | num_basins | | |
| fcode | | | | FCode | |
| date | SRC_DATE | BgnDate | photo_year | FDate | |
| max_width | WIDTH | | mean_width | | |
| max_length | LENGTH | Lmax | max_length | | |
| Slope | | Slope | | | |
| aspect | | Aspect | | | |
| connect | | Connect | | | |
| surging | | Surging | | | |
| linkages | | Linkages | | | |
| form | | Form | | | |

| | | | | | |
|---|---|---|---|---|---|
| term_type | | TermType | | | |
| x_coord | | CenLon | lon | | X_COORD |
| y_coord | | CenLat | lat | | Y_COORD |
| prime_class | PRIMECLASS | | | | |
| frontal_char | | | FRONTAL_CHAR | | |
| long_char | | | long_char | | |
| tongue_act | | | tongue_activity | | |
| moraines1 | | | moraines1 | | |
| moraines2 | | | moraines2 | | |
| source_nourish | | | src_noursh | | |
| min_elev_exp | | | minelv_exp | | |
| mean_elev_acy | | | meanelv_ab | | |
| mean_elev_abl | | | meanelv_ac | | |
| activity_start | | | activ_strt | | |
| activity_end | | | activ_end | | |
| snowline_acy | | | snwln_accu | | |
| snowline_date | | | snwln_date | | |
| mean_depth | | | mean_depth | | |
| deapth_acy | | | depth_acy | | |
| area_acy | | | area_acy | | |
| area_exp | | | area_exp | | |
| mean_width | | | mean_width | | |
| mean_length | | | max_length | | |
| max_len_ex | | | max_len_ab | | |
| max_len_ab | | | max_len_ex | | |
| orient_acc | | | orient_abl | | |
| orient_abl | | | orient_acc | | |
| Remarks | PROC_DESC | | | | |
| Shape_length | Shape_Length | Shape_Length | | Shape_Length | Shape_Length |
| Shape_area | Shape_Area | Shape_Area | | Shape_Area | Shape_Area |
| geom | geom | geom | | geom | geom |

By cross-referencing all the measured attributes in each glacial inventory, it enabled a completeness of attributes was met and that as many attributes as possible were included. This came to a total of 56 attributes for glaciers_variable. The other glacier table, glaciers_static, only contains 10 attributes shown in Figure 2. The attributes for glaciers_static are as follows: the glacier's ID in this database, ID's from the various glacial inventories, the glaciers name (if applicable), and the ID of a parent icemass (if applicable).

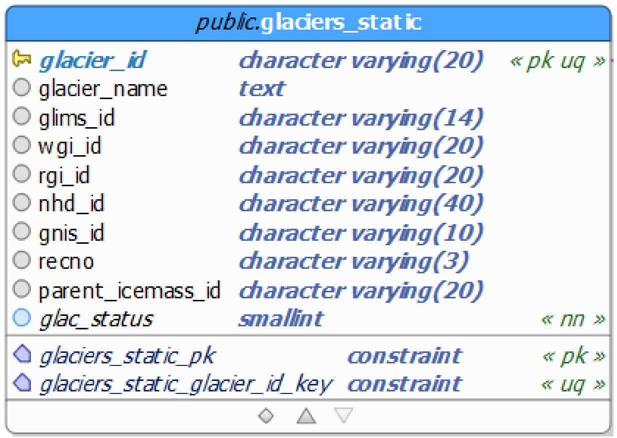


Figure 2 glacier_static Table

The data in this project can be broken down into five categories, shown in Table 2. Glaciers, Jurisdictional Boundaries, Glacial/Hydrological Regions, Submission Information, and Attachments.

Table 2 Data Description

| **Dataset** | **Content** | **Data Format** | **Spatial Display** | **Data Source** |
|---|---|---|---|---|
| California Glacial Inventory | This will contain a shapefile with attributes about each glacier. | Shapefile/GDB | Point and Polygon | GLIMS, RGI, WGI, USGS, Glaciers of the American West |
| Drainage Basin/Hydrology | Hydrology of California | Shapefile/GDB | Polygon | USGS |
| Jurisdictional Boundaries (County, City, Etc.) | Various Jurisdictional Boundaries within California | Shapefile | Polygon | Census Bureau |
| Submission Information | Information about who/what/when glacial data was submitted. | Tables | Table | Glacial Inventories |
| Attachments | Imagery and LIDAR of Glaciers | Raster, Various File Formats (pdf etc.) | Varies | Various |

The next section will cover the identification of these features, how they were obtained, why they were chosen, what they contain, and how they were integrated into the geodatabase.

### *3.1.2. Identification of Features*

In addition to the two glacier features, there are four polygon feature classes and four tables included in the geodatabase.

#### 3.1.2.1. glac_regions (Polygon Feature Class)

This polygon shapefile was obtained through Glaciers of the American West and is a polygon feature that outlines the glacial regions within California (Basagic 2011). The two features shown in Figure 3 are the mountain ranges with areas that contain glaciers. The boundaries of this feature closely match the current glacier extents and help to lead the user of the web map more directly to the glaciers. This data was imported using the using the PostGIS 2.0 Shapefile and DBF Loader and Exporter tool.

| FID | Shape | ID | MTNREGION |
|---|---|---|---|
| 0 | Polygon | 5 | Cascade Range, CA |
| 1 | Polygon | 22 | Sierra Nevada Mount... |

Figure 3 glac_region Features

#### 3.1.2.2. wbdhu6 (Polygon Feature Class)

This dataset was obtained through the U.S. Geological Survey National Hydrography Dataset. This the boundary data for the six-digit or third level hydrologic unit or basin for the California hydrologic region. In Figure 4, a selection of attributes from five of the 24 hydrological basins that are in some part contained within California. This data was included to show the areas which a glacier could drain, but additional levels of the hydrography data set were excluded because data is easily obtained and is unnecessary for many types of analysis. This data was imported using the PostGIS 2.0 Shapefile and DBF Loader and Exporter tool.

| tnmid | metasource | sourcedata | sourceorig | sourcefeat | loaddate | gnis_id | areaacres | areasqkm | states |
|---|---|---|---|---|---|---|---|---|---|
| {98E70FA8-71E6-4D5... | <Null> | <Null> | <Null> | <Null> | 4/20/2018 | 0 | 3494393.15 | 14141.32 | CA,MX |
| {7C49260F-5D97-47F... | <Null> | <Null> | <Null> | <Null> | 6/11/2012 | 0 | 6703528.67 | 27128.24 | CA,OR |
| {EC5C66B8-BFCD-42... | <Null> | <Null> | <Null> | <Null> | 4/20/2018 | 0 | 1779787.8 | 7202.55 | CA |
| {2DFCC869-2C3C-4D... | <Null> | <Null> | <Null> | <Null> | 5/14/2018 | 0 | 15305057.9 | 61937.43 | CA,NV |
| {150932B0-CE4F-46B... | <Null> | <Null> | <Null> | <Null> | 11/6/2017 | 0 | 10040723.85 | 40633.4 | CA,OR |

Figure 4 Example of wbdhu6 Feature Class Attributes

3.1.2.3. ca_counties (Polygon Feature Class)

This dataset was obtained through the U.S. Census Bureau's Tiger/Line Shapefiles. This contains the adjusted boundaries of California counties. This feature was included so that users such as policy makers can determine which glaciers fall within their jurisdictional boundaries. Figure 5 below, shows a sample of attributes of the 58 counties within California. This data was imported using the PostGIS 2.0 Shapefile and DBF Loader and Exporter tool.

| statefp | countyfp | countyns | geoid | name | namelsad | lsad | classfp | mtfcc | csafp | cbsafp | metdivfp | funcstat | aland | awater |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06 | 091 | 00277310 | 06091 | Sierra | Sierra County | 06 | H1 | G4020 | <Nul... | <Null> | <Null> | A | 2468694587 | 23299110 |
| 06 | 067 | 00277298 | 06067 | Sacramento | Sacramento County | 06 | H1 | G4020 | 472 | 40900 | <Null> | A | 2499183617 | 76073827 |
| 06 | 083 | 00277306 | 06083 | Santa Barbara | Santa Barbara County | 06 | H1 | G4020 | <Nul... | 42200 | <Null> | A | 7084000598 | 2729814515 |
| 06 | 009 | 01675885 | 06009 | Calaveras | Calaveras County | 06 | H1 | G4020 | <Nul... | <Null> | <Null> | A | 2641820834 | 43806026 |
| 06 | 111 | 00277320 | 06111 | Ventura | Ventura County | 06 | H1 | G4020 | 348 | 37100 | <Null> | A | 4773390489 | 945942791 |

Figure 5 Example of ca_counties Feature Class Attributes

3.1.2.4. ca_places (Polygon Feature Class)

This dataset was obtained through the U.S. Census Bureau's Tiger/Line Shapefiles. ca_places includes incorporated cities as well as census designated-places (referred to hereafter as CDP). A census-designated place is a population that is identified by the Census Bureau for statistical purposes only but is currently an unincorporated community. While there are no cities or CDPs that contain glaciers, there are cities and CDPs that are close to glaciers, both in the Sierra Nevada and Cascade Ranges. This data was imported using the PostGIS 2.0 Shapefile and DBF Loader and Exporter tool.

| FID | Shape | STATEFP | PLACEFP | PLACENS | GEOID | NAME | NAMELSAD | LSAD | CLASSFP | PCICBSA | PCINECTA | MTFCC | FUNCSTAT | ALAND | AWATER | INTPTLAT | INTPTLON |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | Polygon | 06 | 66140 | 02411785 | 0666140 | San Fernando | San Fernando city | 25 | C1 | N | N | G4110 | A | 6148697 | 0 | +34.2886519 | -118.4362413 |
| 1 | Polygon | 06 | 14190 | 02409487 | 0614190 | Cloverdale | Cloverdale city | 25 | C1 | N | N | G4110 | A | 7863863 | 59201 | +38.7959624 | -123.0153700 |
| 2 | Polygon | 06 | 16560 | 02410240 | 0616560 | Cotati | Cotati city | 25 | C1 | N | N | G4110 | A | 4869007 | 8380 | +38.3284920 | -122.7100491 |
| 3 | Polygon | 06 | 65042 | 02411779 | 0665042 | San Buenaventura (V... | San Buenaventura (V... | 25 | C1 | Y | N | G4110 | A | 56500370 | 27033715 | +34.2677796 | -119.2542062 |
| 4 | Polygon | 06 | 30014 | 02410601 | 0630014 | Glendora | Glendora city | 25 | C1 | N | N | G4110 | A | 50251851 | 403066 | +34.1449667 | -117.8476672 |
| 5 | Polygon | 06 | 32548 | 02410720 | 0632548 | Hawthorne | Hawthorne city | 25 | C1 | N | N | G4110 | A | 15750339 | 28946 | +33.9147753 | -118.3480828 |

Figure 6 Example of ca_places Feature Class Attributes

3.1.2.5. submission_info (Table)

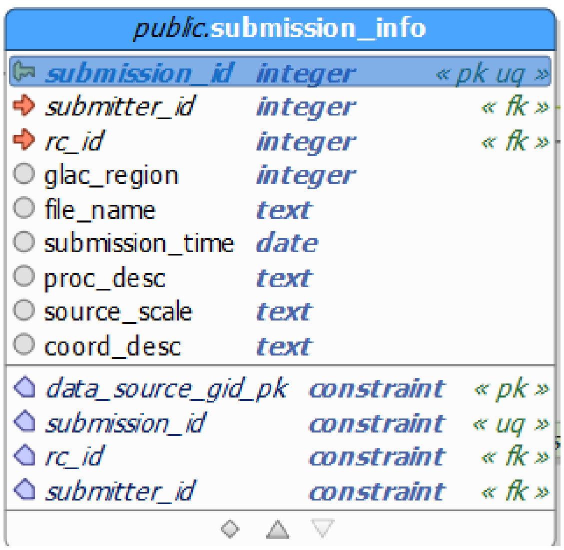


Figure 7 submission_info Table Attributes

This table was created to track submissions of data sources for glacial features so that in the future changes can be updated and tracked over time. It includes attributes, seen in Figure 7, such as file name, submission time, coordinate description, ID of the submitter who contributed the data, a unique ID to track changes over time, etc. The initial information in this tables comes from the five glacial inventories that were used to populate this database. Because the data sources generally had a single analyst submitting the information at a single point in time, rather than trying to extract the information from the sources attributes tables, the information in this table was manually added into table using SQL in pgAdmin.

3.1.2.6. regional_center (Table)

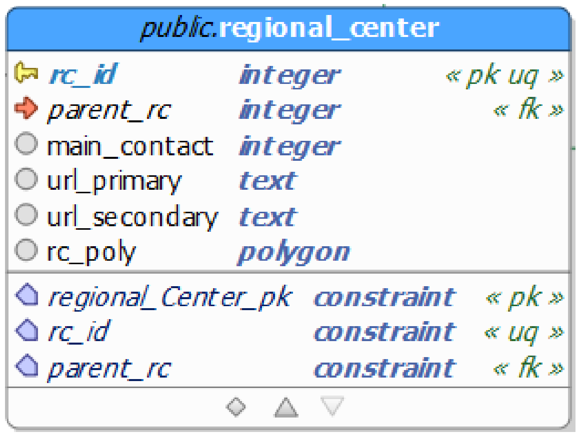


Figure 8 regional_center Table Attributes

Because multiple individuals from a single group can perform or submit analysis, the regional_center table was created to track the groups in which the users belong. This table contains the ID for the regional center, primary contact, and URLs of the regional center. This table can reference itself if there are sub-groups within a primary group that need to be recorded. Like the submission_info table above the information in this table was manually added into table using SQL in pgAdmin.

3.1.2.7. people (Table)

This table contains general information on the persons who have submitted data to the data sets that were used as a part of this project. The attributes, shown in Figure 9, contains information such as name, address, URL, and phone numbers. This information is included for multiple reasons, such as: to track who has updated or added information, track users' permissions, and helps to get in contact with the submitter of an analysis in case of any questions. Because of the initial low number of users to be added, the information was manually added into table using SQL in pgAdmin.

| public.people | | |
|---|---|---|
| contact_id | integer | « pk » |
| surname | text | |
| givennames | text | |
| prof_title | text | |
| affiliation | text | |
| department | text | |
| address1 | text | |
| address2 | text | |
| city | text | |
| state_province | text | |
| postal_code | text | |
| country_code | character(2) | |
| office_loc | text | |
| url_primary | text | |
| url_secondary | text | |
| workphone_primary | text | |
| workphone_secondary | text | |
| workfax | text | |
| homephone | text | |
| mobilephone | text | |
| email_primary | text | |
| email_secondary | text | |
| comment | text | |
| people_pk | constraint | « pk » |

Figure 9 people Table Attributes

3.1.2.8. attachments (Table)

This table contains links to attachments that are linked to each glacier's ID and has a URL of where the attachment is hosted, attachment type, and date of attachment. This enables the web interface of attachments pertaining to each glacier to be displayed by selecting an outline or performing a query.

| public.attachments | | |
|---|---|---|
| attach_name | text | « pk » |
| glacier_id | character varying(20) | |
| file_type | character varying(4) | |
| URL | text | |
| adate | date | |
| editor | text | |
| author | text | |
| description | text | |
| glacier_id_glaciers_variable | character varying(20) | « fk » |
| attachments_pk | constraint | « pk » |
| glaciers_variable_fk | constraint | « fk » |

Figure 10 attachments Table Attributes

### *3.1.3. Choice of Software*

The software that was used for this project is typical of many open source database GIS projects. The only non-open source software is the ESRI ArcGIS suite of software. The final output of this project is a geodatabase and a web map interface. The final output plus the author's familiarity with ESRI applications lead the choices of software used. That, along with the fact that the data from this project's database and web map should be preserved for use past the lifetime of the project, lead to the combination of open-source and ESRI software.

#### 3.1.3.1. Database Software

This project used pgAdmin to manage the spatial database. pgAdmin is the administrative and development platform on the popular open-source database system PostgreSQL. It allows for the storing and maintenance of spatial and non-spatial data. This software is well supported and provides a long-term stable database solution.

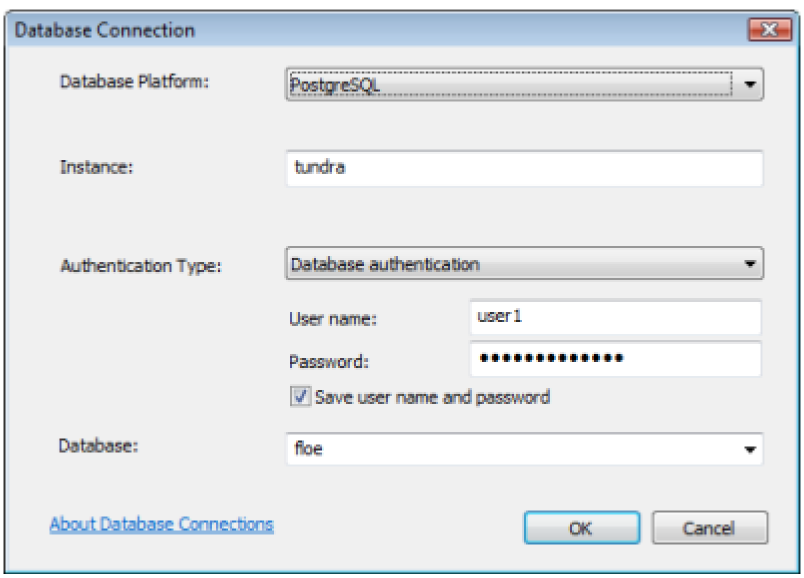


Figure 11 Postgre SQL Connection in ArcGIS Pro. Source: ESRI 2019.

Amazon Web Service (AWS) provides a stable hosting platform for the geodatabase and provides easy linkage between PostgreSQL and ArcGIS Pro. This is done simply by using the Add Database Connection Function and then filling in required fields, see an example in Figure 11. The Instance box will contain the web address of the AWS instance server.

#### 3.1.3.2. GIS Software

The GIS software used for this project was ArcGIS Pro. This software was used to create and manage the spatial data along and create maps for the web map application.

#### 3.1.3.3. Web Application Software

ArcGIS Online was used as the web application software. This software displays the web map and feature services in internet browsers such as Google Chrome or Mozilla Firefox. Esri and Amazon have created a workflow that allows for easy data connection between AWS, PostgreSQL, and ArcGIS Pro. This ease of workflow allowed for a seamless deployment of the web map.

## 3.2. Implementation of Geodatabase

### *3.2.1. Geodatabase structure*

Having defined the features and tables above, along with their attributes, Figure 12 shows a simplified ERD of the features classes and tables that make up the database. Additionally, all the keys and relationships between the components of the database are displayed in Figure 12, showing the overall structure of the database.

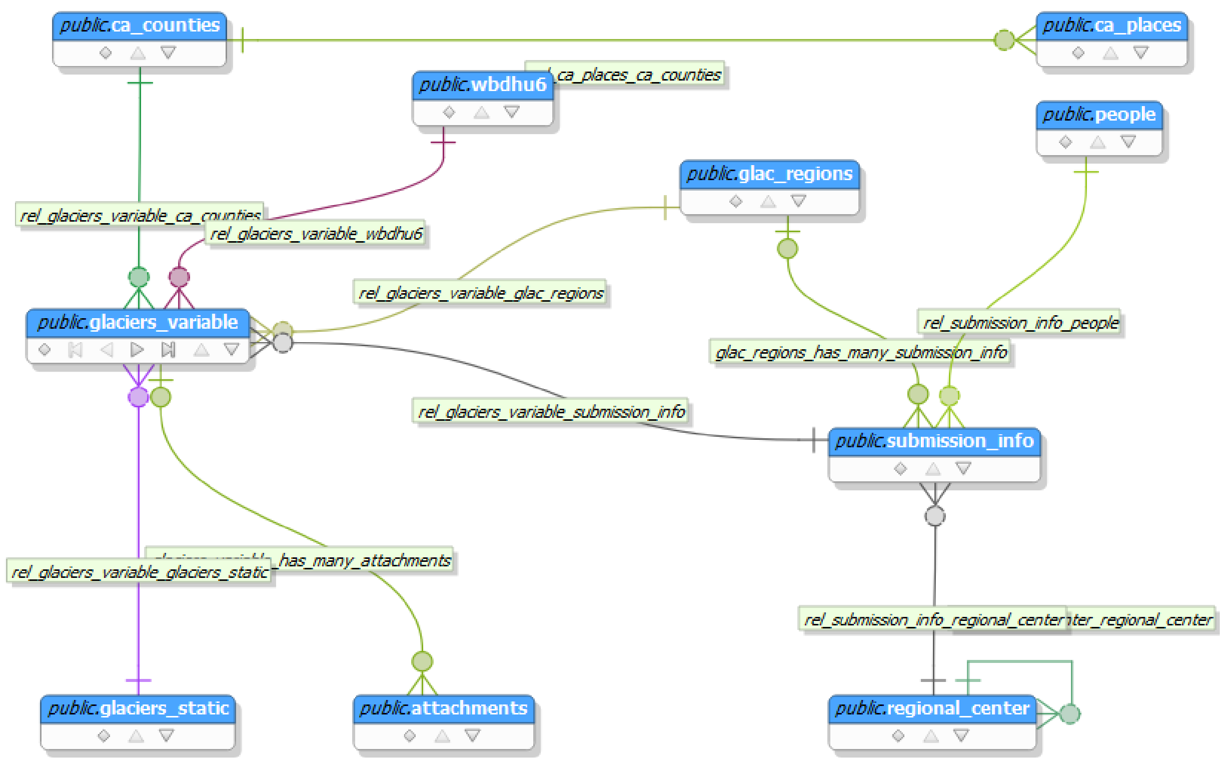


Figure 12 Geodatabase Simplified ERD

pgModeler was used to create and edit the database model. This allowed for the ability to generate SQL based on the model built, and then use that SQL to create the tables in pgAdmin. An important step in this process was to make sure that the primary, foreign, and unique keys were identified to allow the relations between the different tables to ensure quality and that data is not duplicated. Additionally, pgModeler can export the designed model to PostgreSQL. Once the database model was designed and built, the AWS instance was set up and the database connections were established.

### *3.2.2. AWS Set Up*

To create a PostgreSQL database in AWS there were several steps that needed to be followed. First, was to go into the AWS management console and select RDS (Relational Database Service) under Database to open the Amazon RDS console. From there the chose

Create database, and the options presented in **Error! Reference source not found.** were chosen. At this point the database instance was configured, many of the Instance specification options were kept at the default, but DB instance class was changed to “db.t2.micro --- 1 vCPU, 1 GIB RAM” Figure 14 shows the instance settings that were chosen, namely the name of the instance, a master username, and a master password. The name, username, and password were later used to create the database connections with the software used in this project.

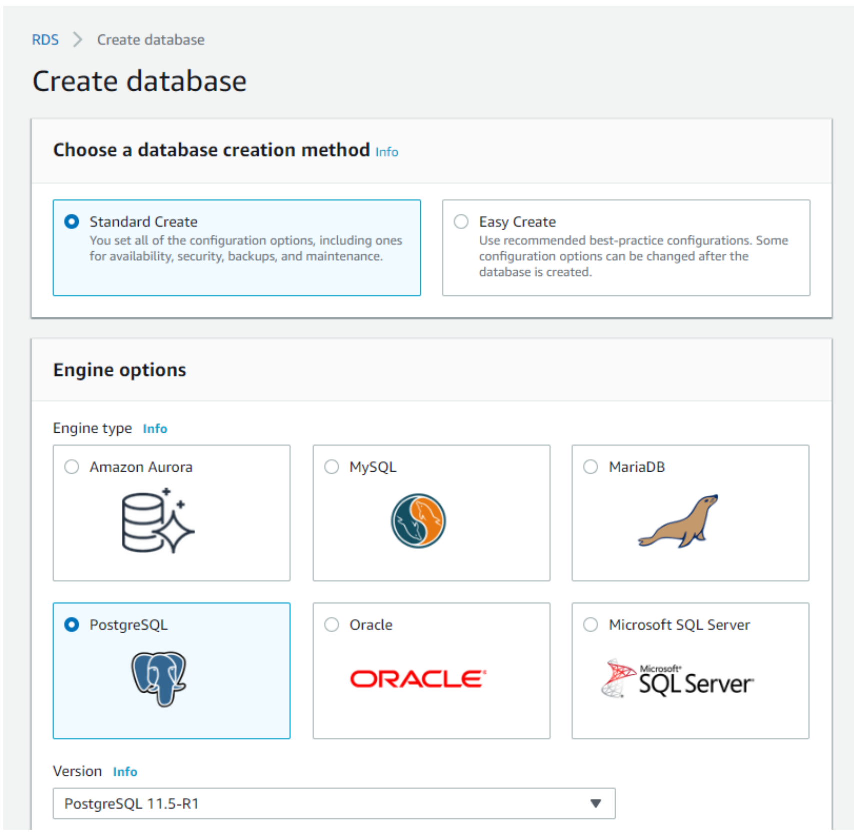


Figure 13 Creating a PostgreSQL DB Instance in AWS

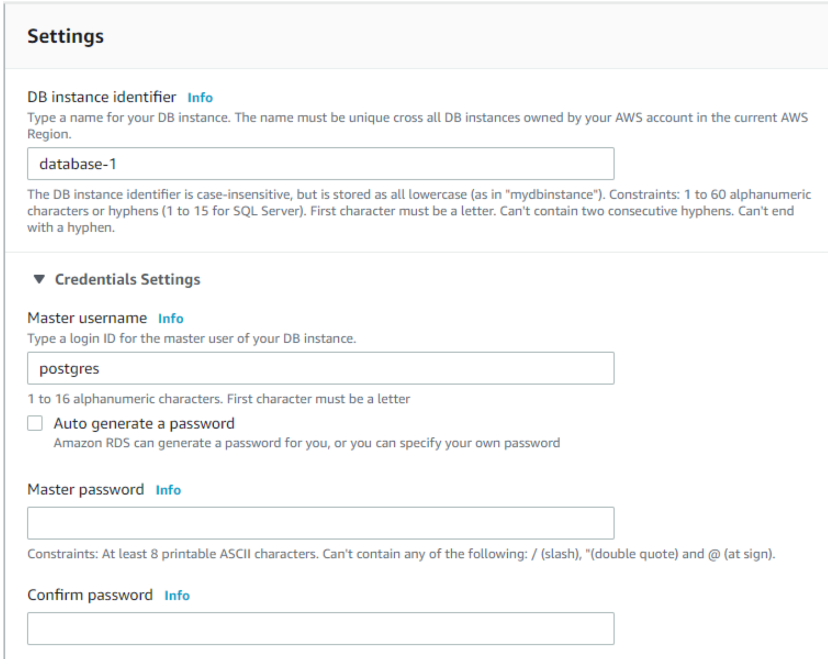


Figure 14 DB Instance Settings

After the initial instance settings were configured, the advance settings had to be chosen. Again, while most options were left on the default, a few items had to be changed because they had to have the proper item selected to insure interoperability between the software and database. Under Network & Security, public accessibility needed to be changed to ‘Yes’ and under Database options a Database name had to be chosen the DB parameter group changed to ‘default.postgres11’ and ‘IAM DB authentication’ enabled. Which can be seen in Figure 15. Once all the settings were configured the database could be created and the connections between it and the software made.

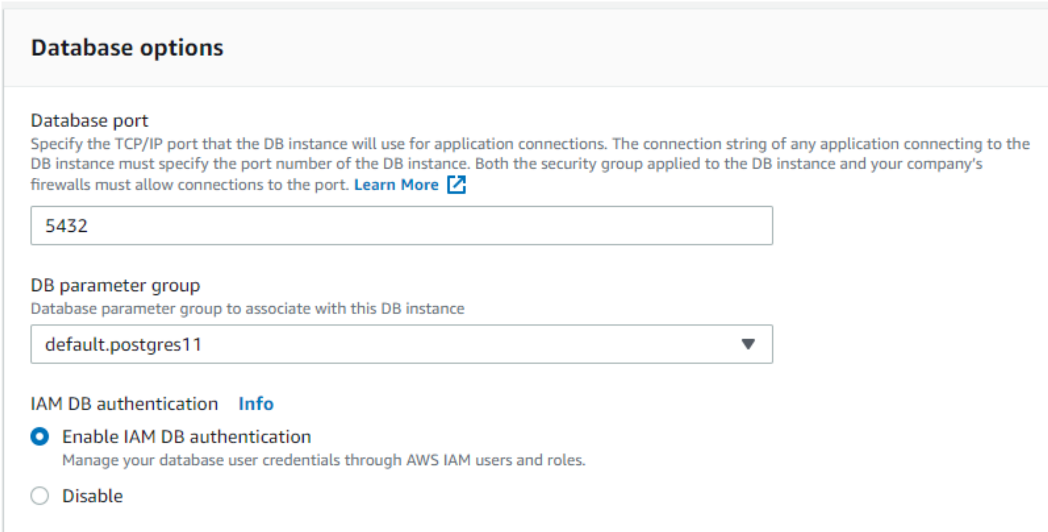


Figure 15 AWS Database Options

### *3.2.3. Database Connections*

There were four connections that had to be established for this database: AWS to ArcGIS Pro, AWS to pgAdmin, AWS to pgModeler, and AWS to PostGIS Shapefile Import/Export Manager. Shown below in Figure 16 and Figure 17 are the screens for connection ArcGIS Pro and pgAdmin to a database instance server. The process is relatively simple, all that needed to be done was enter the instance or host address, port, username, and password. Creating the connections allowed for importing, editing, and managing for the data on the AWS server.

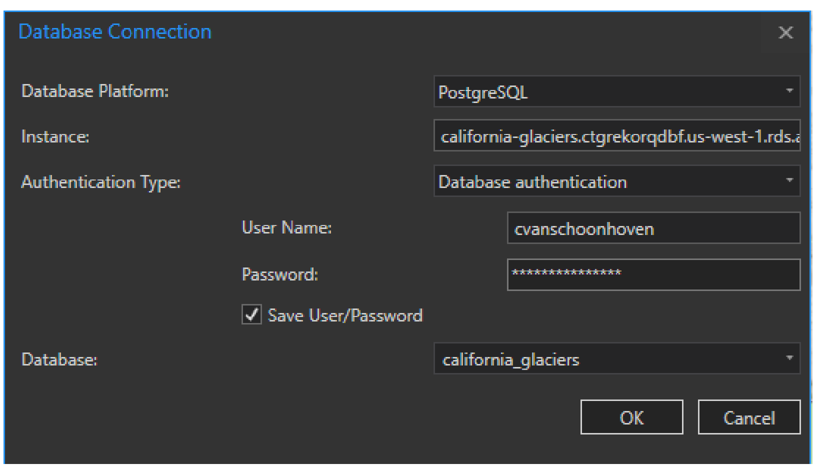


Figure 16 Database Connection for AWS to ArcGIS Pro

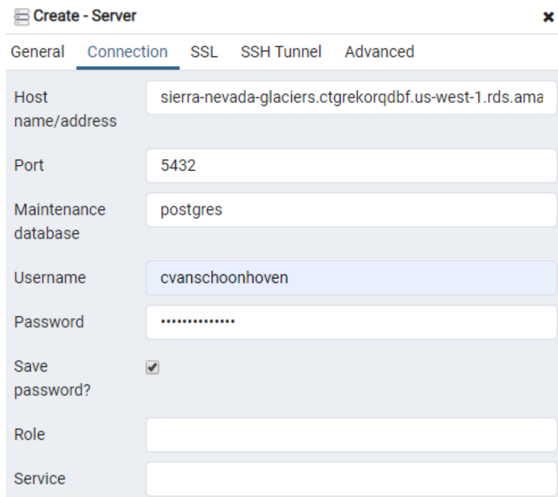


Figure 17 Database Connection for AWS to pgAdmin

### *3.2.4. Creation of SQL Tables from Source Data*

Once the connections were established, the author was able to begin establishing the table structure within the database. This was first done by using the SQL produced from pgModeler in pgAdmin's Query Tool to create the glaciers_static, glaciers_variable, attachments, people, regional_center, and submission_info tables. The code was saved as a SQL file then copied into the Query Tool and run, creating the table with the required keys, constraints, and dependencies. Below is a sample of SQL code was used to create the attachments table. SQL code for the remaining tables can be found in Appendix G SQL Code.

```
CREATE TABLE public.attachments (
    attach_name text NOT NULL,
    glacier_id character varying(20),
    file_type character varying(4),
    "URL" text,
    adate date,
    editor text,
    author text,
    description text,
    glacier_id_glaciers_variable character varying(20),
    CONSTRAINT attachments_pk PRIMARY KEY (attach_name)
```

```
);
COMMENT ON COLUMN public.attachments.adate IS 'data of publication';
ALTER TABLE public.attachments OWNER TO cvanschoonhoven;
```

### *3.2.5. Importing Shapefiles*

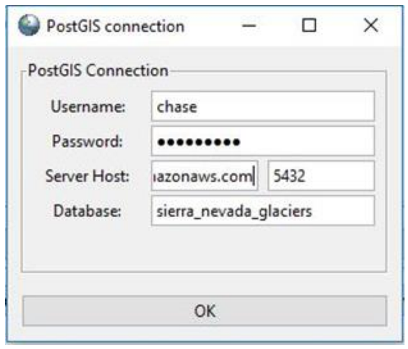


Figure 18 Example of PostGIS 2.0 Shapefile and DBF Loader and Exporter Tool

The shapefiles glac_regions, wbdhu6, ca_counties, and ca_places were then imported into the geodatabase using the Shapefile and DBF Loader and Exporter Tool. This tool comes with the standard PostGIS installation. To import files using this tool the author created a connection to the AWS geodatabase. Figure 18, shows and example connection screen for the shapefile loader. Once the shapefiles were imported, the constraints of each feature class needed to be honored. This was done using the Query Tool in pgAdmin to run SQL code that altered the tables based on the required constraints. Additionally, in pgAdmin the properties of each table were examined to make sure the columns, constraints and other parameters matched those from the ERD, and corrections were made as required. Once the database was designed and implemented, the web map was created.

## 3.3. Web Map Creation

*3.3.1. Domain Acquisition & Construction*

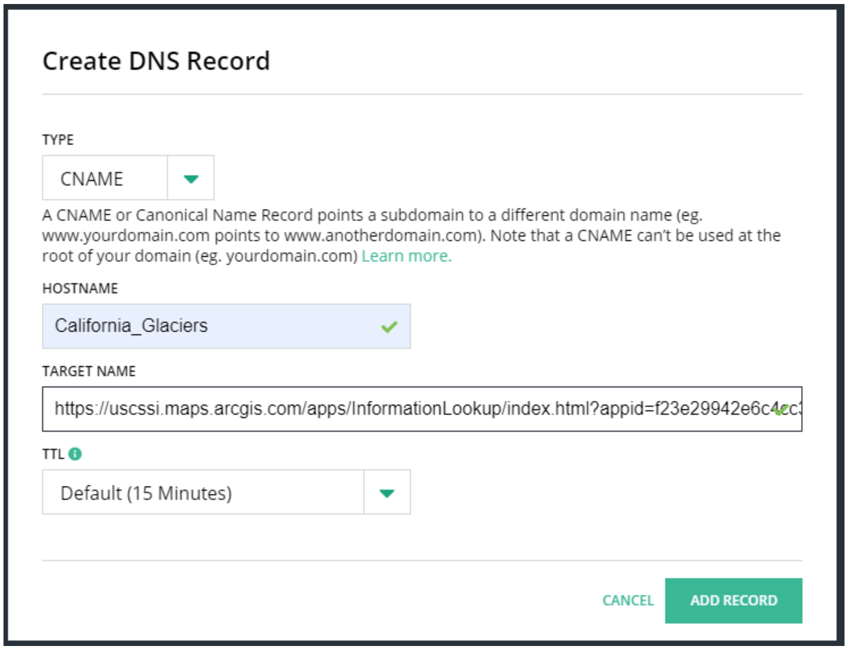


Figure 19 Example of Creating a New DNS Record for Domains Registered at Hover.com

In undertaking the creation of a web map, a domain was purchased and constructed. Web access allows more people within the specified user groups to easily access the data that this project presents. The author owns several domains, including mapping.cool which is currently being used to host the web map at the subdomain california-glaciers at the following link: mapping.cool/california-glaciers. This was done by editing the DNS record for the domain and creating a new DNS record that points to the target URL of the ArcGIS Web App. An example of this can be seen in Figure 19 for hover.com which is the authors domain registrar of choice. The hosting of the data for the web map was done through AWS which has several tiers including free tiers which will allow for a low-cost hosting of the project into the future.

This project is also stored at GitHub, which is a free online storage repository for version control, this GitHub repository holds the geodatabase, data, methods, maps, and layouts used for this project, and can be found at the following link: https://github.com/krevee/california_glaciers. This allows this project to be continued and iterated on even if the author is no longer able to host the data and web map.

### *3.3.2. Web Application*

The web application used to share this project was ArcGIS web maps and web map application. These two applications allowed seamless integrations between AWS, pgAdmin, and ArcGIS Pro. To integrate the data from the database into the web application the author had to add the data from the geodatabase into ArcGIS Pro and then share each data layer as a web layer in ArcGIS Pro. Once this was done the layers were added to a web map. Inside the web map the author was able to symbolize and layout the map.

Once the data layers were added to the web map, the web map was then brought into the Web AppBuilder for ArcGIS where the theme, layout, map, widgets, and attributes where able to be configured to the desired parameters. Figure 20 shows the option to ‘Choose web map’ and select from ‘My Content’ which web maps to add. The top left corner of Figure 20 also shows the ‘Theme’ and ‘Widget’ tabs which contain various tools for configuring the Web App. A simple template was chosen to allow for easy navigation by any user. Additionally, only a small selection of tools, Select, Summary, and Measurement, were chosen. These tools were chosen for their important but simple functionality in the initial iterations of the web map.

The next section covers the geoprocessing methods of the glacial data final geodatabase design that allowed the final web map and GitHub repository to be created. Along with an evaluation perspective on the final database and web map.

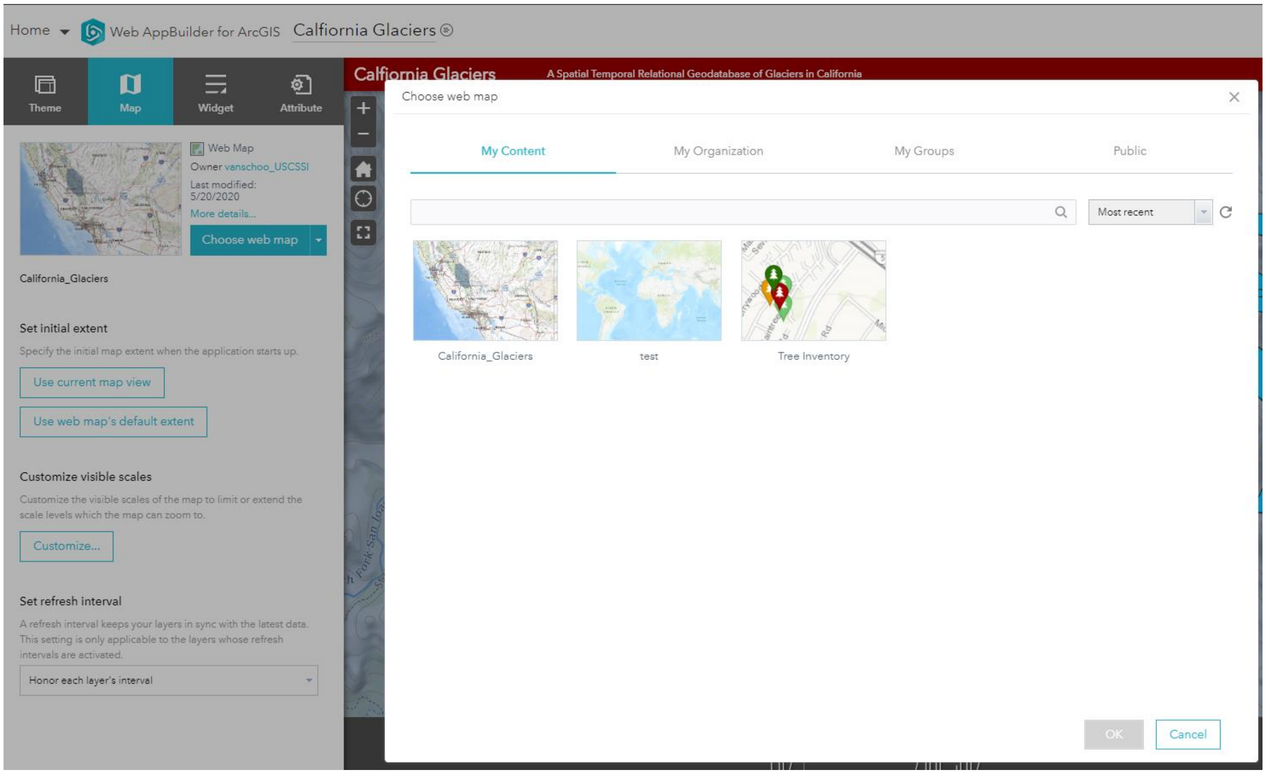


Figure 20 Selecting a Web Map in Web Application Builder for ArcGIS

# Chapter 4 Results

The glacial geodatabase was not considered finalized until it was presented to a wider audience. This was done through the web map and GitHub repository initially discussed in section three of Chapter 3. This chapter presents the final geodatabase design, the final web map, and GitHub repository. The final results of the work completed in this thesis are available through either the web map or GitHub repository, which includes: a geodatabase, documents covering the methodology used, a collection of other documents and source materials, and a number of maps that may be used to share and visualize the data presented. All the glacial data used was acquired from public sources and remains available to the public through the availability at the GitHub repository.

## 4.1. Geodatabase Final Design

In the previous chapter, the attribute, features, design, and implementation of the geodatabase was explained. Now that all of the parts of the geodatabase have been explained, the final geodatabase design is shown in Figure 21. This shows an expanded ERD of the features classes and tables that make up the database along with their corresponding attributes and domain values. All the keys and relationships between the components of the database are displayed in Figure 21, showing the complete structure of the database.

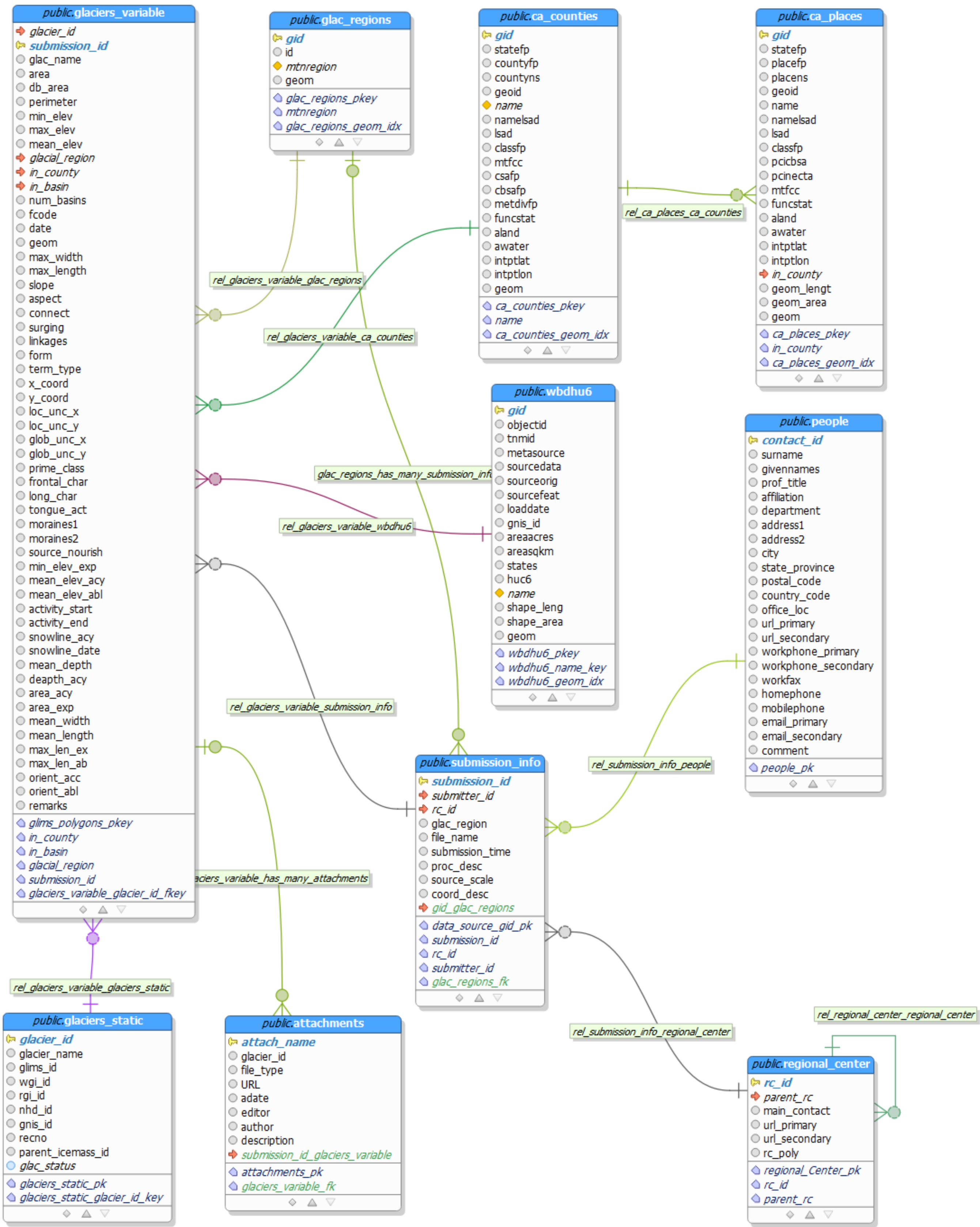


Figure 21 Final ERD

The ERD in Figure 21 shows how the tables and attributes of the tables are connected in the geodatabase through primary and foreign keys, as well the unique values in each table. This shows the linkage between the data tables and shows how each table relates and works together. This was determined by the design and implementation that was discussed in the previous chapter.

## 4.2. Final Web Map

A view of the final web map displaying glaciers near the June Lake area along with the California places polygons is shown in Figure 22. The top right corner of the web map has five layers that can be turned on or off, glaciers_variable, ca_counties, ca_places, wbhu6, and glac_regions. The top right also has a Legend that can be expanded or contracted. The top left of the web map contains various tools that can be used to navigate and search the web map, including a search bar that can be used to search the feature layers as well as the ArcGIS World Geocoding Service. The bottom of the web map shows a scale, the current location of the map and sources.

The web map shows 5435 glacial features at various points in time, and contains 2670 unique glaciers, two glacial regions, 24 water basins, 58 counties, and 1552 census places. Each of these layers' attribute tables can be viewed, and item details can be brought up which includes additional details, sources, and metadata.

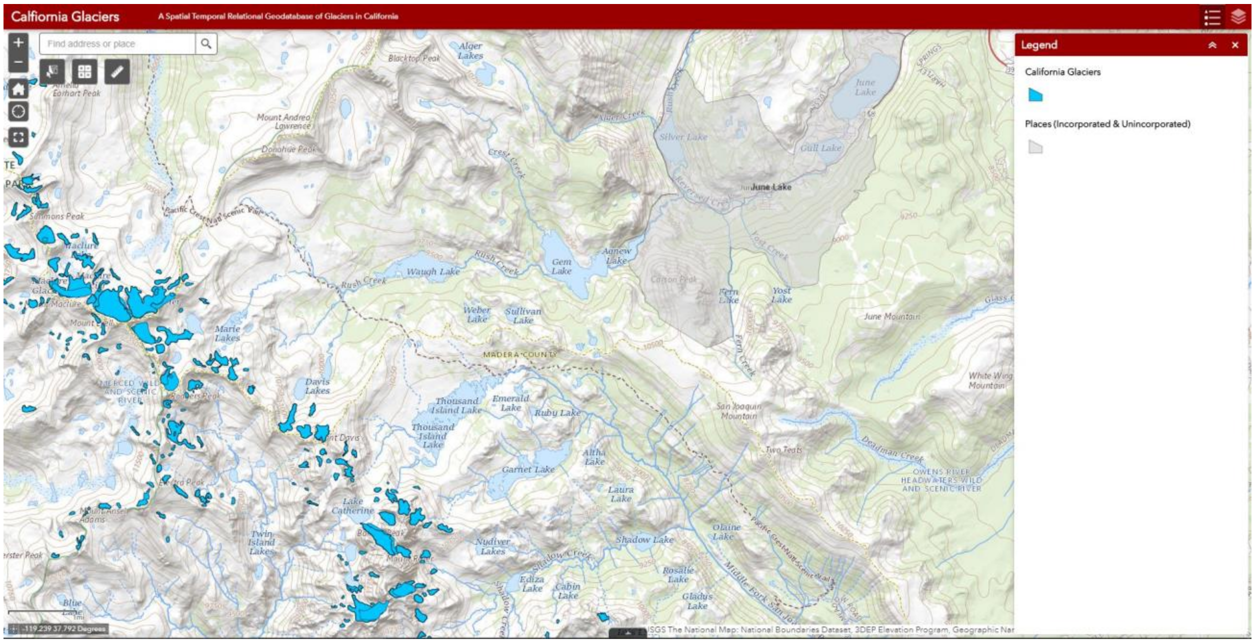


Figure 22 California Glaciers Web Map

## 4.3. GitHub Repository

In addition to the web map, the final result of the work completed in this thesis project can be found in a GitHub Repository. GitHub is free online storage repository that provides project hosting and version control which now holds the geodatabase, data, methods, documentation, maps, and sources for this project. The GitHub account is krevee and the project is california_glaciers and the contents of the project are summarized in Table 3.

Table 3 GitHub Repository Contents

| **Folder Names** | **Content** |
|---|---|
| Data | Project data and source data |
| ERD_Files | ERD Images and dbm files |
| GDB_Files | Geodatabase files |
| Maps_Layout_Files | Project maps and layours |
| SQL Queries | SQL queries and tasks |
| README.md | Read me file |

To view the contents of a folder, one clicks on the desired folder name. For example, one might choose the 'Data' folder to the display data and source data of the project. To download or view the files in a repository, GitHub provides a large green button on the right-hand side shown in Figure 23 California Glaciers GitHub Repository. The README file contains an explanation, details, and versioning information on this project. A README is normally the first place to look when beginning a project.

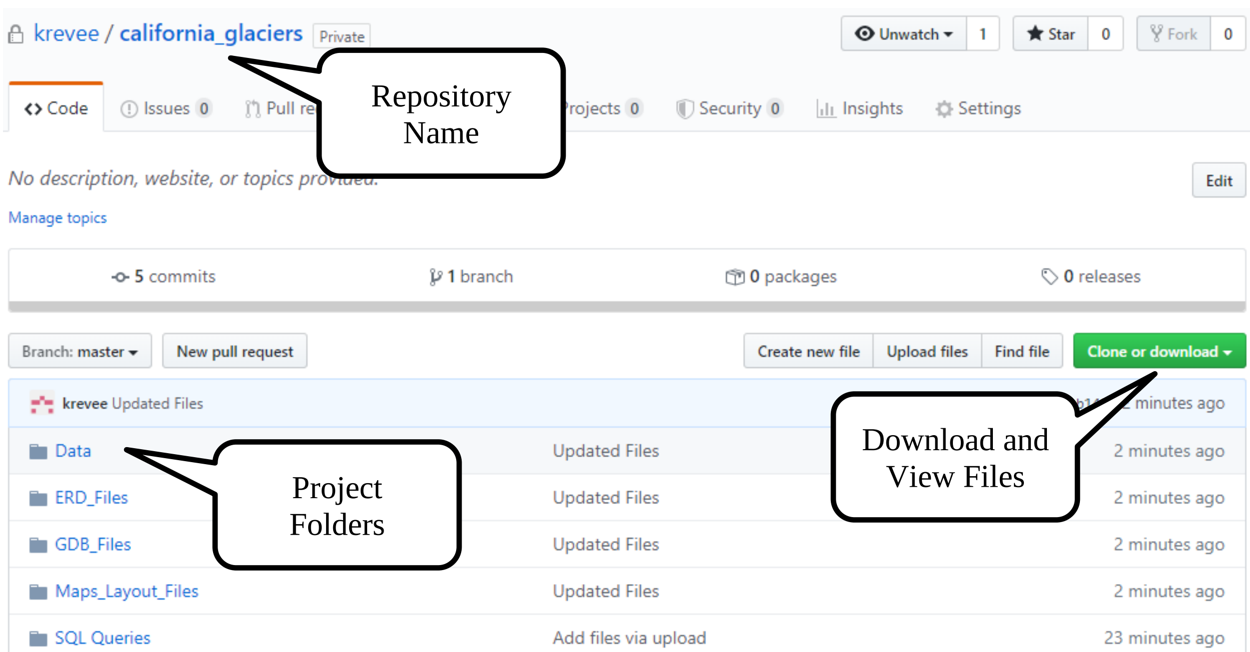


Figure 23 California Glaciers GitHub Repository

# Chapter 5 Conclusion

As glaciers are changing rapidly, mapping glacial changes is becoming more and more important. This database enables better monitoring and tracking of changes to glaciers in California. By diving into existing glacial datasets and models and refining them, this thesis shows that the goals outlined at the beginning of this project were met. This chapter evaluates the project, explores ways it may be enhanced in the future, and discusses lessons learned throughout.

## 5.1. Evaluation

There are many ways in which a database can be evaluated. It can be measured by a variety of benchmarks such as depth of the information contained within, width or how many topics the database covers, the accuracy of the data it holds, how recent the data it contains is, the level of completeness of the stored data, the connectivity and design quality, the usability, and the cost to build, host, and manage the database. Many of these topics are discussed earlier in this thesis when establishing the parameters and goals of the project. Cost is not covered because there was little cost as the software licenses and data were freely available or made free through student licenses and only the fee was for hosting the AWS. This section will be an assessment of the database level of completeness.

When examining the completeness of a glacial inventory database, it can be complete in a variety of manners such are all of the glacier in the studied region contained in the database or is there a completeness of attributes about each glacier. Though, because of the nature of a glacier they are constantly changing in size, shape, etc. which makes a database never truly complete. In addition, because of climate change, many glaciers are disappearing which means there may be less glaciers than what an inventory shows.

This project includes all publicly available glacial data for California, so in terms of number of glaciers tracked it is complete in that regard. This project also attempted to have a completeness of attributes by including and refining existing glacial data. Though in terms of temporal this coverage this project is more complete than other glacial inventories, it is still lacking because of this type of data. The most recent data collection was from 2017 by the NHD which means it has been over 2 years since the glaciers have been inventoried. In the time period between data collection, many changes to or loss of glaciers may go unrecorded. One improvement to this lack of data could come from collecting glacial changes via volunteered public information. Of course, this data would need to be verified by an authority, however it could aid in more rapid collection and analysis of changes to the glaciers. A multi-source approach could provide an improvement over the authoritative-only approach which currently has long periods between updates. This is discussed further in the next section.

## 5.2. Future Work

There should be three main areas of focus were this project to continue further. The first would be to conduct a survey with potential users to help improve use cases and functionality. Next would be additional web map features and functionality. The last area of improvement would be an increase of the scope to a national implementation. These improvements would help to strengthen this project for not only California, but also the entire country.

### *5.2.1. Web GIS Evaluation Survey*

The survey would be constructed to help determine the effectiveness of the web map. This survey would be helpful in connecting the demographics and background of users with how they interact with the web map. It could also be used to determine if the web map was useful to the various user groups outlined in Chapter 2. It could also allow for respondents to suggest ways in which the web map could be improved. This could help refine the user interface and user experience. It could also help with additional tool and widget choices that would be the most useful. The survey could use a variety of questions types such as multiple choice, short answers, and scale-based in its evaluation. The results, even from a small sample, would help further iterations of the web map be more usable to the target audience.

### *5.2.2. Additional Web Map Functionality*

There are several improvements that would help the functionality of the web map. First would be the addition of analysis widgets in the web map. There are currently some analysis tools available in Web AppBuilder for ArcGIS but the testing and implementation was too prohibitive time-wise to include them in the current project. One such tool would be the Time Slider widget; this tool enables a better view of the temporal elements of the map and could play an animation that shows how the data changes over time. To add this widget would require reformatting of the date/time elements of the 5435 glacier features, which vary in format from each data source. One method to automate the reformatting would be using a python script to help simply the task.

Another improvement would be the addition of the ability for users to submit data to this project. Currently, the author is the only one who can add, remove, or edit data, but since so many others are studying glaciers it would be good to have the ability for others to submit new data to this project. This would be an extremely complicated addition that would need serious vetting so that the integrity of the data would be maintained. This would likely need to be done through a different application than Web AppBuilder and brought back into the model after the data was evaluated.

*5.2.3. National Implementation*

Another improvement would be to implement the project on a national scale. A unified geodatabase of all glaciers in the United States would be a complex project that would involve many interest groups and municipalities. For a project of such a large scope to succeed, all the groups would need to agree on the database design, structure, and implementation, as well as deliverable milestones. These were all things that were either determined by the author or part of the constraints of this thesis project, but for a public project those tasks would be navigated and negotiated by many parties. There would be many decisions as what attributes to include and what their definitions are, for example what qualifies as “surging” for a glacier, in addition to others. There are many important choices to be made before a glacial geodatabase could be implemented on a national level. Once a consensus is reached as to the design, structure, implementation, and data collection for the geodatabase, data from projects such as this one could be incorporated into it. It would then be the responsibility of municipalities, other government agencies, private institutions and even citizen scientists to contribute. This type of collaboration tactic is like the U.S. Census Bureau’s Community TIGER portal discussed by Otto (2015) for the National Address Database.

## 5.3. Final Thoughts

This project set out to meet three criteria. The first was to develop the database in such a way that it can store glacial data in such a way that meets the current requirements and standards of existing global glacial databases. Next was to archive and store the large amounts of glacial data collected by USGS, GLIMS, RGI, WGI, and GAW. The third was to make the data easily accessible through a web map and Github repository. As a result of the work completed in this thesis, these goals have been met. This project made a spatiotemporal geodatabase for California glaciers that is comprehensive, easy to access and use, and helps to highlight the changes to the glaciers over time. By researching existing databases and datasets, design was improved, and a greater temporal resolution was stored and archived. But this is only a first step, and the institutions responsible for glacier stewardship need to take up the task of collecting and managing glacial data and building upon the framework that this project presents.

As pointed out in the introduction to this thesis, glaciers can provide a multitude of benefits and hazards to people and the environment. Improved glacial monitoring using glacial databases can help to track the changes over time. As well as study those changes, we can implement policies that can help protect this valuable natural resource.

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# Appendix A List of Attributes from GLIMS

| Field name | Description |
|---|---|
| LINE_TYPE | Category of line segment. Possible values include: "glac_bound" (glacier boundary), "intrnl_rock" (internal rock outcrop, or nunatak), "snowline", "centerline" (center flowline of the glacier). |
| ANLYS_ID | The ID assigned within GLIMS for a particular outline of a glacier at a particular time. |
| GLAC_ID | The GLIMS glacier ID |
| ANLYS_TIME | Representative time the analysis was carried out. |
| AREA | Map-plane area of the glacier, as provided by the analyst, km2. |
| DB_AREA | Map-plane area of the glacier, as calculated within the GLIMS Glacier Database, km2. |
| WIDTH | Representative width of the glacier, meters. |
| LENGTH | Representative length of the glacier, meters. |
| PRIMECLASS | Primary WGMS classification of the glacier. |
| MIN_ELEV | Elevation of the lowest part of the glacier, in meters above sea level. |
| MEAN_ELEV | Mean elevation of the glacier, in meters above sea level. |
| MAX_ELEV | Elevation of the highest part of the glacier, in meters above sea level. |
| SRC_DATE | The as-of date for the outline. Usually the acquisition date of the image. |
| REC_STATUS | Record status (should always be "okay" for downloaded data). |
| GLAC_NAME | Glacier name. |
| WGMS_ID | Glacier ID assigned by the World Glacier Monitoring Service. |
| LOCAL_ID | An ID assigned by the GLIMS Regional Center or institution that supplied the data. |
| SUBM_ID | ID assigned by GLIMS to the entire data submission. |
| RELEASE_OK | Date after which the data is released. |
| PROC_DESC | Description of the processing done to create the glacier outlines. |
| SUBMIT_SUR | Surname of the person submitting the data. |
| SUBMIT_GIV | Given names of the person submitting the data. |
| SUBMIT_AFF | Affiliation of the person submitting the data. |
| SUBMIT_URL | URL for the submitting institution. |
| SUBMIT_CCO | Country code for the submitting institution. |
| ANLST_SURN | Surname of the analyst. |
| ANLST_GIVN | Given names of the analyst. |
| ANLST_AFFL | Affiliation of the analyst. |
| ANLST_URL | URL related to the analyst. |
| ANLST_CCOD | Country code for the analyst. |
| CHIEF_SURN | Surname of the chief of the Regional Center. |
| CHIEF_GIVN | Given names of the chief of the Regional Center. |
| CHIEF_AFFL | Affiliation of the chief of the Regional Center. |
| RC_URL | URL for the Regional Center. |
| RC_CCODE | Country code for the Regional Center. |
| RC_ID | GLIMS ID for the Regional Center. |

| | |
|---|---|
| GEOG_AREA | Geographic region covered by the Regional Center. |

# Appendix B List of Attributes from RGI

| Field Name | Description |
|---|---|
| RGIId | A 14-character identifier of the form RGIvv-rr.nnnnn, where vv is the version number, rr is the first order region number and nnnnn is an arbitrary identifying code that is unique within the region. These codes were assigned as sequential positive integers at the first-order (not second-order) level, but they should not be assumed to be sequential numbers, or even to be numbers. In general, the identifying code of each glacier, nnnnn, should not be expected to be the same in different RGI versions. |
| GLIMSId | A unique 14-character identifier in the GLIMS format GxxxxxxEyyyyyΘ, where xxxxxx is longitude east of the Greenwich meridian in millidegrees, yyyyy is north or south latitude in millidegrees, and Θ is N or S depending on the hemisphere. The coordinates of GLIMSId agree with CenLon and CenLat (see below). |
| BgnDate,EndDate | The date of the source from which the outline was taken, in the form yyyymmdd, with missing dates represented by -9999999. When a single date is known, it is assigned to BgnDate. If only a year is given, mmdd is set to 9999. Only when the source provides a range of dates is EndDate not missing, and in this case the two codes together give the date range. In version 6.0, 98% of glaciers (by area; 99% by number) have date information (Figure 2). Figure 3 shows date-range spans for glaciers with date ranges. 85% of the ranges are shorter than four years. Many of the ranges of three years (36-47 months) are from the 1999–2003 period between the launch of Landsat 7 and the failure of the scan-line corrector of its ETM+ sensor. |
| CenLon, CenLat | Longitude and latitude, in degrees, of a single point representing the location of the glacier. These coordinates agree with those in GLIMSId. |
| O1Region, O2Region | The codes of the first-order and second-order regions (Table 2) to which the glacier belongs. |
| Area | Area of the glacier in km2, calculated in cartesian coordinates on a cylindrical equal-area projection of the authalic sphere of the WGS84 ellipsoid, or, for nominal glaciers, accepted from the source inventory. |
| Zmin, Zmax | Minimum and maximum elevation (m above sea level) of the glacier, obtained in most cases directly from a DEM covering the glacier. For most of the nominal glaciers Zmin and Zmax were taken from the parent inventory, WGI or WGI-XF. |
| Zmed | Median elevation (m) of the glacier, chosen by sorting the elevations of the DEM cells covering the glacier and recording the 50th percentile of their cumulative frequency distribution. The mean elevation of the glacier |

<table>
<tr><td></td><td>is not provided explicitly in the RGI but can be recovered with fair accuracy from the hypsometric list.</td></tr>
<tr><td>Slope</td><td>Mean slope of the glacier surface (deg), obtained by averaging single-cell slopes from the DEM.</td></tr>
<tr><td>Aspect</td><td>The aspect (orientation) of the glacier surface (deg) is presented as an integer azimuth relative to 0° at due north. The aspect sines and cosines of each of the glacier’s DEM grid cells are summed and the mean aspect is calculated as the arctangent of the quotient of the two sums.</td></tr>
<tr><td>Lmax</td><td>Length (m) of the longest surface flowline of the glacier. The length is measured with the algorithm of Machguth and Huss (2014). Briefly, points on the glacier outline at elevations above Zmed are selected as candidate starting points and the flowline emerging from each candidate is propagated by choosing successive DEM cells according to an objectively weighted blend of the criteria of steepest descent and greatest distance from the glacier margin. The latter criterion can be understood as favouring “centrality”, especially on glacier tongues. The longest of the resulting lines is chosen as the glacier’s centreline.</td></tr>
<tr><td>Status</td><td>The Status attribute flags glaciers whose outlines await subdivision or are nominal circles:
<table>
<tr><td>Value</td><td>Status</td></tr>
<tr><td>0</td><td>Glacier or ice cap</td></tr>
<tr><td>1</td><td>Glacier complex</td></tr>
<tr><td>2</td><td>Nominal glacier</td></tr>
<tr><td>9</td><td>Not assigned</td></tr>
</table></td></tr>
<tr><td>Connect</td><td>The Connect attribute records the connectivity level developed by Rastner et al. (2012) for glaciers in Greenland. Glaciers that are physically detached from the ice sheet have a connectivity level of 0. A glacier is weakly connected if it is in contact with the ice sheet only at a well-defined divide in the accumulation zone, and strongly connected if the divide is indistinct in the accumulation zone and/or confluent with an ice-sheet outlet in the ablation zone:
<table>
<tr><td>Value</td><td>Connect</td></tr>
<tr><td>0</td><td>No connection</td></tr>
<tr><td>1</td><td>Weak connection</td></tr>
<tr><td>2</td><td>Strong connection</td></tr>
<tr><td>9</td><td>Not assigned</td></tr>
</table></td></tr>
<tr><td>Form</td><td>The Form attribute contains information on the form of the ice body:
<table>
<tr><td>Value</td><td>Form</td></tr>
<tr><td>0</td><td>Glacier</td></tr>
<tr><td>1</td><td>Ice Cap</td></tr>
<tr><td>2</td><td>Perennial snowfield</td></tr>
<tr><td>3</td><td>Seasonal snowfield</td></tr>
<tr><td>9</td><td>Not assigned</td></tr>
</table></td></tr>
<tr><td>TermType</td><td>The TermType attribute contains information on terminus type. Lake-terminating glaciers are identified as such only in Alaska, the Southern Andes and Antarctica; elsewhere they currently have TermType equal to</td></tr>
</table>

| | |
|---|---|
| | 0. Where more than one value applies to a given terminus, the dominant type as interpreted from satellite imagery is chosen.<br>Value – TerminusType:<br>0 – Land-terminating<br>1 – Marine-terminating<br>2 – Lake-terminating<br>3 – Dry calving<br>4 – Regenerated<br>5 – Shelf-terminating<br>9 – Not assigned |
| Surging | The Surging attribute contains information on evidence for surging and is based on the inventory of Sevestre and Benn (2015). Value Surging 0 1 2 Probable 3 Observed 9 Not assigned<br>Value – Surging:<br>0 – No evidence<br>1 – Possible<br>2 – Probable<br>3 – Observed<br>9 – Not assigned |
| Linkages | The Linkages attribute indicates whether the ancillary file 00_RGI60_LINKS.CSV contains a link to mass-balance measurements in the Fluctuations of Glaciers database. To date 232 linkages have been identified.<br>Value – Linkages:<br>0 – Not in FG<br>1 – In FG<br>9 – Not assigned |
| Name | Name of the glacier, or the WGI or WGI-XF id code (modified after Müller et al., 1978) if available. Many glaciers do not have names, and coverage of those that do is incomplete. Of the 215,547 glaciers in RGI 6.0, 46,770 have information in their Name field, although for many the content is actually an id code. |

In version 5.0 the contents of the fields RGIFlag and GlacType were rearranged (see below). In version 4.0 six topographic attributes were added to the main shapefile entry for each glacier, with each glacier having a hypsometric list stored in a separate regional file. Each glacier had 12 data attributes in version 3.2 and 10 in version 2.0.

# Appendix C List of Attributes from WGI

**WGI_GLACIER_ID**
**Description:** A 12-character unique glacier identifier. The ID number is assigned to the glacier as defined by the WGMS convention that forms the glacier ID number by combining the five following elements:
2-character political unit
1-digit continent code
4-character drainage code
2-digit free position code
3-digit local glacier code
**No Data Value:** Mandatory field; WGMS has replaced any missing digit with zero.

**POLITICAL_UNIT**
**Description:** 2-character abbreviation for the name of the country or territory in which the glacier is located. These codes are ISO3166 country codes from the ISO Maintenance Agency for Country Codes. Table 1 contains the country codes used in the WGI.
**No Data Value:** Mandatory field

**CONTINENT_CODE**
**Description:** 1-digit code for the continent in which the glacier is located. The six continent codes used in the database are listed in Table 2.
**No Data Value:** Mandatory field

**DRAINAGE_CODE**
**Description:** 4-character drainage basin code in which the glacier is located. "The study area must then be divided and subdivided into drainage basins of first-order (A-Z), second-order (0-9), third-order (0-9) and, if necessary, fourth-order (A-Z), see supplement Identification" (Müller et al. 1977). According to WGMS 1989 the fourth-order digit of the drainage code may also be (0-9).
**No Data Value:** Mandatory field; WGMS has replaced any missing digit with zero.

**FREE_POSITION_CODE**
**Description:** 2-digit identification numbers freely chosen by the investigator, usually used as logical continuation of the DRAINAGE_CODE.
**No Data Value**: Mandatory field; WGMS has replaced any missing digit with zero.

**LOCAL_GLACIER_CODE**
**Description:** 3-digit local glacier code freely chosen by the investigator, usually used as logical continuation of the DRAINAGE_CODE and FREE_POSITION_CODE
**No Data Value**: Mandatory field; WGMS has replaced any missing digit with zero.

**GLACIER_NAME**
**Description:** 30-character name of the glacier. "If a name is too long a meaningful abbreviation of it should be entered. The spelling of the name must be in the Latin alphabet and may consist only of the following characters: A B C D E F G H I J K L M N O P Q R S T U V W X Y Z"

(Müller et al. 1977). Note: If necessary, the name can be abbreviated; in which case the full name is given in the REMARKS field.
**No Data Value**: Null

**LAT**
**Description:** The latitude of the glacier in decimal degrees North or South; up to 7 digits. Positive values indicate the Northern Hemisphere and negative values indicate the Southern Hemisphere. Latitude is given to a maximum precision of 4 decimal places."The point on the glacier whose coordinates are given should be in the upper part of the ablation area, in the main stream and sufficiently high so as not to be lost if the glacier retreats" (Müller et al. 1977).
**No Data Value**: Mandatory field

**LON**
**Description:** The longitude of the glacier in decimal degrees East or West; up to 7 digits. Positive values indicate east of the zero meridian and negative values indicate west of the zero meridian. Longitude is given to a maximum precision of 4 decimal places.
**No Data Value**: Mandatory field

**EASTING**
**Description:** Easting of local coordinate in UTM or other nationally determined format, up to 9 digits. Format is described in the COORDINATE_DESCRIPTION field.
**No Data Value**: Null

**NORTHING**
**Description:** Northing of local coordinates in UTM or other nationally determined format, up to 9 digits. Format is described in the COORDINATE_DESCRIPTION field.
**No Data Value**: Null

**COORDINATE_DESCRIPTION**
**Description:** Datum and projection or type of other formats can be given here (UTM zone, name of coordinate system, etc.), up to 50 characters.
**No Data Value**: Null

**NUM_BASINS**
**Description:** The number of basins a glacier drains into, 1-digit integer. According to Müller et al (1977), "An ice mass will often drain into several drainage basins (treated as separate units of the identification code) but cannot be split into separate units. The total number of drainage basins should be given in this field, e.g. 1 for one drainage basin. For identification purposes, however, the ice mass should be assigned to the drainage basin which contains the largest portion of the surface area."
**No Data Value**: Null

**TOPO_YEAR**
**Description:** The 4-digit year of the topographic map used for measurements of glacier elevation. **Note:** If more than one topographic map was used, the most relevant year is recorded in this field; and the others used are recorded in the REMARKS field.

**No Data Value**: Null

**TOPO_SCALE**
**Description:** The scale of the topographic map used for measurements of glacier parameters, up to 7 digits. The values in this field are filled in as the reciprocal of the scale (1:25000 for the example below). Note: If more than one topographic map was used, the most relevant scale is recorded here; and the others used are recorded in the REMARKS field.
**No Data Value**: Null

**PHOTO_YEAR**
**Description:** The 4-digit year of the photograph used for measurements of glacier parameters. **Note:** If more than one photograph were used, the most relevant year is recorded here; and the others used are recorded in the REMARKS field. In general, the glaciers outlines; and hence, the values for area and length; were determined from aerial photographs, so we recommend using the PHOTO_YEAR for glacier area values. However, the elevation information usually comes from topographic maps, so TOPO_YEAR should be used for elevation values.
**No Data Value**: Null

**MAX_ELEV**
**Description:** Maximum elevation of the highest point of the glacier in meters above sea level, up to 4 digits.
**No Data Value**: Null

**MEAN_ELEV**
**Description:** The mean elevation is the altitude of the contour line, in meters above sea level, that halves the area of the glacier, up to 4 digits.
**No Data Value**: Null

**MIN_ELEV**
**Description:** The minimum elevation of the lowest point of the glacier in meters above sea level, up to 4 digits.
**No Data Value**: Null

**MIN_ELEV_EXP**
**Description:** Minimum elevation exposed is the altitude of the lowest point of the total surface area of the glacier, in meters above sea level, that is not covered with coarse stone material, up to 4 digits.
**No Data Value**: Null

**MEAN_ELEV_ACC**
**Description:** Mean elevation accumulation is the altitude of the contour line, in meters above sea level, that halves the accumulation area of the glacier, up to 4 digits.
**No Data Value**: Null

**MEAN_ELEV_ABL**

**Description:** Mean elevation ablation is the altitude of the contour line, in meters above sea level, that halves the ablation area of the glacier, up to 4 digits.
**No Data Value**: Null

**PRIMARY_CLASS**
**Description:** A 1-digit code that describes the primary classification of the glacier. The codes are described in Table below.
**No Data Value**: Null

| Code | Name | Description |
|---|---|---|
| 0 | Miscellaneous | Any type not listed below. |
| 1 | Continental Ice Sheet | Inundates areas of continental size. |
| 2 | Ice Field | Ice masses of the sheet or blanket type with a thickness that is insufficient to obscure the subsurface topography. |
| 3 | Ice Cap | Dome-shaped ice masses with radial flow. |
| 4 | Outlet Glacier | Drains an ice sheet, ice field, or ice cap, usually of valley glacier form; the catchment area may not be easily defined. |
| 5 | Valley Glacier | Flows down a valley; the catchment area is well defined. |
| 6 | Mountain Glacier | Cirque, niche type, crater type, or hanging glacier; also includes ice aprons and groups of small units. |
| 7 | Glacieret and Snowfield | Small ice masses of indefinite shape in hollows, river beds, or on protected slopes that have developed from snow drift, avalanches, and/or particularly heavy accumulation in certain years. Usually no marked flow pattern is visible; and it has been in existence for at least two consecutive years. |
| 8 | Ice Shelf | Floating ice sheet of considerable thickness attached to a coast nourished by a glacier or glaciers; snow accumulation on its surface or bottom freezing. |
| 9 | Rock Glacier | Lava-stream-like debris mass containing ice in several possible forms and moving slowly downslope. |

**FORM**
**Description:** A 1-digit code that describes the form of the glacier. Table below describes the glacier form codes.
**No Data Value**: Null

| Code | Name | Description |
|---|---|---|
| 0 | Miscellaneous | Any type not listed below. |

| | | |
|---|---|---|
| 1 | Compound Basins | Two or more individual valley glaciers issuing from tributary valleys and coalescing (Fig. 1a). |
| 2 | Compound Basin | Two or more individual accumulation basins feeding one glacier system (Fig. 1b). |
| 3 | Simple Basin | Single accumulation area (Fig. 1c). |
| 4 | Cirque | Occupies a separate, rounded, steep-walled recess which has formed on a mountain side (Fig. 1d). |
| 5 | Niche | Small glacier in a V-shaped gully or depression on a mountain slope (Fig. 1e); generally more common than genetically further-developed cirque glacier. |
| 6 | Crater | Occurring in extinct or dormant volcanic craters. |
| 7 | Ice Apron | Irregular, usually thin ice mass which adheres to mountain slopes or ridges. |
| 8 | Group | A number of similar ice masses occurring in close proximity to one another but are too small to be assessed individually. |
| 9 | Remnant | Inactive, usually small ice masses left by a receding glacier. |

**FRONTAL_CHAR**
**Description:** A 1-digit code that describes the frontal characteristics of the glacier. Table below lists the frontal characteristic codes.
**No Data Value**: Null

| **Code** | **Name** | **Description** |
|---|---|---|
| 0 | Miscellaneous | Any type not listed below. |
| 1 | Piedmont | Ice field formed on a lowland area by lateral expansion of one or coalescence of several glaciers (Fig. 2a, 2b). |
| 2 | Expanded Foot | Lobe or fan formed where the lower portion of the glacier leaves the confining wall of a valley and extends on to a less restricted and more level surface (Fig. 2c). |
| 3 | Lobed | Part of an ice sheet or ice cap, disqualified as an outlet glacier (Fig. 2d). |
| 4 | Calving | Terminus of a glacier sufficiently extending into sea or lake water to produce icebergs; includes- for this inventory- dry land ice calving which would be recognizable from the "lowest glacier elevation." |
| 5 | Confluent | Coalescing, non-contributing (Fig. 2e). |
| 6 | Irregular, mainly clean ice (mountain or valley glaciers). | |
| 7 | Irregular, mainly debris-covered (mountain or valley glaciers). | |

| | |
|---|---|
| 8 | Single lobe, mainly clean ice (mountain or valley glaciers). |
| 9 | Single lobe, mainly debris-covered (mountain or valley glaciers). |

**LONGI_PROFILE**
**Description:** A 1-digit code that describes the longitudinal profile of the glacier. Table below describes the codes.
**No Data Value**: Null

| Code | Name | Description |
|---|---|---|
| 0 | Miscellaneous | Any type not listed below. |
| 1 | Even/Regular | Includes the regular or slightly irregular and stepped longitudinal profile. |
| 2 | Hanging | Perched on a steep mountain side, or in some cases issuing from a steep hanging valley. |
| 3 | Cascading | Descending in a series of marked steps with some crevasses and sÃ©racs. |
| 4 | Ice Fall | A glacier with a considerable drop in the longitudinal profile at one point causing heavily broken surface. |
| 5 | Interrupted | Glacier that breaks off over a cliff and reconstitutes below. |

**SOURCE_NOURISH**
**Description:** 1-digit code that describes the source of nourishment for the glacier. Table below lists the source nourishment codes.
**No Data Value**: Null

| Code | Name |
|---|---|
| 0 | Unknown |
| 1 | Snow |
| 2 | Avalanches |
| 3 | Superimposed ice |

**TONGUE_ACTIVITY**
**Description:** A 1-digit code that describes the activity of the tongue of the glacier. Table below lists the tongue activity codes.
**No Data Value**: Null

| Code | Name |
|---|---|
| 0 | Uncertain |
| 1 | Marked retreat |

| | |
|---|---|
| 2 | Slight retreat |
| 3 | Stationary |
| 4 | Slight advance |
| 5 | Marked advance |
| 6 | Possible surge |
| 7 | Known surge |
| 8 | Oscillating |

**MORAINES1**
**Description:** 1-digit code that refers to moraines in contact with the present-day glacier. Table below describes the moraine codes.
**No Data Value**: Null

| **Code** | **Name** |
|---|---|
| 0 | No moraines |
| 1 | Terminal moraines |
| 2 | Lateral and/or medial moraine |
| 3 | Push moraine |
| 4 | Combination of 1 and 2 |
| 5 | Combination of 1 and 3 |
| 6 | Combination of 2 and 3 |
| 7 | Combination of 1, 2, and 3 |
| 8 | Debris, uncertain if morainic |
| 9 | Moraines, type uncertain or not listed |

**MORAINES2**
**Description:** A 1-digit code that refers to moraines farther downstream of the glacier. Table above describes the moraine codes.
**No Data Value**: Null

**PERIOD_ACTIVITY_START**
**Description:** 4-digit start year of the period for which the tongue activity was assessed. Note: If the period for which the tongue activity was assessed is shorter than one year, this year will be recorded in both fields PERIOD_ACTIVITY_START and PERIOD_ACTIVITY_END.
**No Data Value**: Null

**PERIOD_ACTIVITY_END**

**Description:** 4-digit end year of the period for which the tongue activity was assessed. Note: If the period for which the tongue activity was assessed is shorter than one year, this year will be recorded in both fields PERIOD_ACTIVITY_START and PERIOD_ACTIVITY_END.
**No Data Value**: Null

**SNOW_LINE_ELEV**
**Description:** Altitude of the snow line of the glacier in meters above sea level, up to 4-digits. Note: The glacier data from the former Soviet Union often uses an estimation technique to calculate the snowline. The type of technique used is recorded in the REMARKS field.
**No Data Value**: Null

**SNOW_LINE_ACY**
**Description:** 1-digit snow line accuracy rating. Table below lists the rating values.
**No Data Value**: Null

| **Rating** | **Accuracy (meters)** |
|---|---|
| 1 | 0 - 25 |
| 2 | 25 - 50 |
| 3 | 50 - 100 |
| 4 | 100 - 200 |
| 5 | > 200 |

**SNOW_LINE_DATE**
**Description:** 8-digit date of observation of the snowline of the form YYYYMMDD where YYYY is the 4-digit year, MM is the 2-digit month, and DD is the 2-digit day of month. If part or all of the date is missing, that missing parts are filled with 9's. Note: Snow line elevation is the altitude of the transient snowline at the end of the ablation season or, in most cases and for practical reasons, at the time the photograph was taken.
**No Data Value**: 99999999

**MEAN_DEPTH**
**Description:** The physical depth of the glacier in meters, up to 4 digits. Note I: Mean depth is only be given if actually measured (for instance by drilling or radio-echo soundings). Note II: Many of the values in this field were estimated using a thickness-area relation (Müller et al. 1997 and Müller et al. 1976).
**No Data Value**: Null

**DEPTH_ACY**
**Description:** 1-digit depth accuracy rating. Table below lists the depth accuracy ratings and their values.
**No Data Value**: Null

| **Rating** | **Accuracy (%)** |
|---|---|
| 1 | 0 - 5 |

| | |
|---|---|
| 2 | 5 - 10 |
| 3 | 10 - 20 |
| 4 | 20 - 30 |
| 5 | > 30 |

**TOTAL_AREA**
**Description:** The total area of the glacier in a horizontal projection in square kilometers, up to 6 digits.
**No Data Value**: Null

**AREA_ACY**
**Description:** 1-digit area accuracy rating of the total area. Table below lists the area accuracy ratings and their values.
**No Data Value**: Null

| Rating | Accuracy (%) |
|---|---|
| 1 | 0 - 5 |
| 2 | 5 - 10 |
| 3 | 10 - 15 |
| 4 | 15 - 30 |
| 5 | > 30 |

**AREA_IN_STATE**
**Description:** The total area of the glacier that resides in the political state concerned in a horizontal projection in square kilometers, up to 6 digits.
**No Data Value**: Null

**AREA_EXP**
**Description:** The area of the exposed ice of the glacier in a horizontal projection in square kilometers, up to 6 digits
**No Data Value**: Null

**MEAN_WIDTH**
**Description:** The mean width of the glacier in a horizontal projection in kilometers, up to 4 digits.
**No Data Value**: Null

**MEAN_LENGTH**
**Description:** Mean length of the glacier in a horizontal projection in kilometers, up to 4 digits.
**No Data Value**: Null

**MAX_LENGTH**
**Description:** Maximum length of the glacier in kilometers measured along the most important flowline in a horizontal projection, up to 4 digits.
**No Data Value**: Null

**MAX_LENGTH_EXP**
**Description:** Maximum length, in kilometers, of the exposed ice of the glacier in a horizontal projection, up to 4 digits.
**No Data Value**: Null

**MAX_LENGTH_ABL**
**Description:** Maximum length, in kilometers, of the ablation area of the glacier in a horizontal projection, up to 4 digits.
**No Data Value**: Null

**ORIENTATION_ACC**
**Description:** The 1- to 2-character main orientation of the accumulation area using the 8 cardinal points: N, NW, W, SW, S, SE, E, and NE.
**No Data Value**: Null

**ORIENTATION_ABL**
**Description:**The 1- to 2-character main orientation of the ablation area using the 8 cardinal points: N, NW, W, SW, S, SE, E, and NE.
**No Data Value**: Null

**DATA_CONTRIBUTOR**
**Description:** The institution or persons who contributed the data to NSIDC, up to 255 characters. For full references see the Data Contributors Table.
**No Data Value**: Mandatory field

**REMARKS**
**Description:** Any important information or comments not included in the other fields above are given here, up to 255 characters.
**No Data Value**: Null

# Appendix D List of Attributes from NHD Waterbody

| Field Name | Definition | Comments |
|---|---|---|
| Permanent Identifier | Global ID and GUID data types store registry style strings consisting of 36 characters enclosed in curly brackets. These strings uniquely identify a feature or table row within a geodatabase and across geodatabases. This is how features are tracked in one-way and two-way geodatabase replication. | |
| FDate | Date of last feature modification. | |
| Resolution | Source resolution. Currently NHD is available as separate resolutions. Plans are to develop a single-resolution database holding the highest resolution data with tools to allow for generalization | Domain of values: Local >1:12,000 High 1:24,000/12,000 Medium 1:100,000 |
| GNIS_ID | Unique identifier assigned by GNIS, length 10. | GNIS_ID = “null” if no name associated with the feature |
| GNIS_Name | Proper name, specific term, or expression by which a particular geographic entity is known, length 65. | GNIS_Name = “null” if no name associated with the feature |
| AreaSqKm | Area of areal feature based on Albers Equal Area, length 8. | Computed |
| Elevation | The vertical distance from a given datum. | Stage of the water elevation is encoded in the FCode. |
| ReachCode | Unique identifier composed of two parts. The first eight digits is the subbasin code as defined by FIPS 103. The next six digits are randomly assigned, sequential numbers that are unique within a subbasin, length 14. | Required for all NHDFlowlines. NHDWaterbody and NHDPoint feature classes allow reach codes but does not require them. Ice Mass and Playa do not have reachcodes. |
| WBArea_Permanent_Identifier | Global ID and GUID data types store registry style strings consisting of 36 characters enclosed in curly brackets. These strings uniquely identify a feature or table row within a geodatabase and across geodatabases. This is how features are tracked in one-way and two-way geodatabase replication. | |
| FType | Three-digit integer value; unique identifier of a feature type. | |
| FCode | Five-digit integer value; composed of the feature type and combinations of characteristics and values. | |

| | | |
|---|---|---|
| Shape_Lenth | Length in meters | All features should have a +integer value |
| Enabled | Created when Geometric Network is built | All features should be set to True (From the database).<br>New or modified features will have a Null value until network is rebuilt. |

# Appendix E List of Attributes from Glaciers of the American West

| Attribute Label | Definition |
|---|---|
| FID | Internal feature number. |
| Shape | Feature geometry. |
| AREA | Area calculated in square meters in the NAD_83_Albers_Equal_Area projection |
| PERMIETER | Perimeter calculated in meters in the NAD_83_Albers_Equal_Area projection |
| RECNO | Unique identifier generated by PSU |
| X_COORD | Centroid X in Decimal Degrees |
| Y_COORD | Centroid Y in Decimal Degrees |
| CLASSIFICA | Description |
| SOURCE | Agency or media of origination |
| SRC_SCALE | Scale of feature's original mapping |
| GLACNAME | Name of Glacier |

## Appendix F glaciers_variable Data Dictionary

| Field Name | Description | SQL Data Type | Null able |
|---|---|---|---|
| glacier_id | Glacier identification number | character varying(20) | Yes |
| submission_id | Submission identification number | integer | No |
| glac_name | Name of the glacier | character varying(28) | Yes |
| area | Map-plane area of the glacier | numeric | Yes |
| db_area | Map-plane area of the glacier, as calculated within the GLIMS Glacier Database | numeric | Yes |
| perimeter | Perimeter of the glacier | numeric | Yes |
| min_elev | Lowest elevation of the glacier | numeric | Yes |
| max_elev | Maximum elevation of the glacier | numeric | Yes |
| mean_elev | Mean elevation of the glacier | numeric | Yes |
| glacial_region | Glacial region that the glacier lies within | character varying(20) | Yes |
| in_county | California county that the glacier falls within | text | Yes |
| in_basin | Watershed basin the glaciers lies within | text | Yes |
| num_basins | Number of watershed basins the glacier is within | smallint | Yes |
| fcode | Five-digit integer value; composed of the feature type and combinations of characteristics and values | integer | Yes |
| date | The as-of date for the glacier. Usually the acquisition date of the image used for analysis. | timestamp | Yes |
| max_width | Representative width of the glacier | numeric | Yes |
| max_length | Representative length of the glacier | numeric | Yes |
| slope | Mean slope of the glacier surface | smallint | Yes |
| aspect | The aspect (orientation) of the glacier surface (deg) is presented as an integer azimuth relative to 0° at due north. | smallint | Yes |
| connect | See Description of Connect in Appendix B List of Attributes from RGI | smallint | Yes |
| surging | See Description of Surging in Appendix B List of Attributes from RGI | smallint | Yes |
| linkages | See Description of Linkages in Appendix B List of Attributes from RGI | smallint | Yes |
| form | See Description of Form in Appendix B List of Attributes from RGI | smallint | Yes |
| term_type | See Description of TermType in Appendix B List of Attributes from RGI | smallint | Yes |
| x_coord | Centroid X in Decimal Degrees | numeric | Yes |
| y_coord | Centroid Y in Decimal Degrees | numeric | Yes |
| loc_unc_x | Local uncertainty of x | smallint | Yes |

| | | | |
|---|---|---|---|
| loc_unc_y | Local uncertainty of y | smallint | Yes |
| glob_unc_x | Global uncertainty of x | smallint | Yes |
| glob_unc_y | Global uncertainty of y | smallint | Yes |
| prime_class | Primary WGMS classification of the glacier. | smallint | Yes |
| frontal_char | See Description of Frontal_Char in Appendix B List of Attributes from RGI | smallint | Yes |
| long_char | See Description of Long_Char in Appendix B List of Attributes from RGI | smallint | Yes |
| tongue_act | See Description of Tongue_Activity in Appendix B List of Attributes from RGI | smallint | Yes |
| moraines1 | See Description of Moraines1 in Appendix B List of Attributes from RGI | smallint | Yes |
| moraines2 | See Description of Moraines2 in Appendix B List of Attributes from RGI | smallint | Yes |
| source_nourish | See Description of Source_Nourish in Appendix B List of Attributes from RGI | smallint | Yes |
| min_elev_exp | See Description of Min_Elev_Exp in Appendix B List of Attributes from RGI | smallint | Yes |
| mean_elev_acy | See Description of Mean_Elev_Acy in Appendix B List of Attributes from RGI | smallint | Yes |
| mean_elev_abl | See Description of Mean_Elev_Abl in Appendix B List of Attributes from RGI | smallint | Yes |
| activity_start | See Description of Activity_Start in Appendix B List of Attributes from RGI | smallint | Yes |
| activity_end | See Description of Activity_End in Appendix B List of Attributes from RGI | smallint | Yes |
| snowline_acy | See Description of Snowline_Acy in Appendix B List of Attributes from RGI | smallint | Yes |
| snowline_date | See Description of Snowline_Date in Appendix B List of Attributes from RGI | smallint | Yes |
| mean_depth | See Description of Mean_Depth in Appendix B List of Attributes from RGI | smallint | Yes |
| deapth_acy | See Description of Depth_Acy in Appendix B List of Attributes from RGI | smallint | Yes |
| area_acy | See Description of Area_Acy in Appendix B List of Attributes from RGI | smallint | Yes |
| area_exp | See Description of Area_Exp in Appendix B List of Attributes from RGI | smallint | Yes |
| mean_width | See Description of Mean_Width in Appendix B List of Attributes from RGI | smallint | Yes |
| mean_length | See Description of Mean_Length in Appendix B List of Attributes from RGI | smallint | Yes |
| max_len_ex | See Description of Max_Len_Ex in Appendix B List of Attributes from RGI | smallint | Yes |
| max_len_ab | See Description of Max_Len_Ab in Appendix B List of Attributes from RGI | smallint | Yes |

| | | | |
|---|---|---|---|
| orient_acc | See Description of Orient_Acc in Appendix B List of Attributes from RGI | text | Yes |
| orient_abl | See Description of Orient_Abl in Appendix B List of Attributes from RGI | text | Yes |
| remarks | Additional remarks or notes | text | Yes |

# Appendix G SQL Code

```
-- Database generated with pgModeler (PostgreSQL Database Modeler).
-- pgModeler  version: 0.9.2_snapshot20190921
-- PostgreSQL version: 11.0
-- Project Site: pgmodeler.io
-- Model Author: ---

-- object: rds_iam | type: ROLE --
-- DROP ROLE IF EXISTS rds_iam;
CREATE ROLE rds_iam WITH
   INHERIT
   ENCRYPTED PASSWORD '********';
-- ddl-end --

-- object: rds_ad | type: ROLE --
-- DROP ROLE IF EXISTS rds_ad;
CREATE ROLE rds_ad WITH
   INHERIT
   ENCRYPTED PASSWORD '********';
-- ddl-end --

-- object: cvanschoonhoven | type: ROLE --
-- DROP ROLE IF EXISTS cvanschoonhoven;
CREATE ROLE cvanschoonhoven WITH
   CREATEDB
   CREATEROLE
   INHERIT
   LOGIN
   ENCRYPTED PASSWORD '********';
-- ddl-end --

-- object: rdsrepladmin | type: ROLE --
-- DROP ROLE IF EXISTS rdsrepladmin;
CREATE ROLE rdsrepladmin WITH
   REPLICATION
   ENCRYPTED PASSWORD '********';
-- ddl-end --

-- -- object: rdsadmin | type: ROLE --
-- -- DROP ROLE IF EXISTS rdsadmin;
-- CREATE ROLE rdsadmin WITH
--  SUPERUSER
--  CREATEDB
--  CREATEROLE
--  INHERIT
```

```
--  LOGIN
--  REPLICATION
--  BYPASSRLS
--  ENCRYPTED PASSWORD '********';
-- -- ddl-end --
--
-- object: rds_superuser | type: ROLE --
-- DROP ROLE IF EXISTS rds_superuser;
CREATE ROLE rds_superuser WITH
   INHERIT
   ENCRYPTED PASSWORD '********'
   ROLE cvanschoonhoven;
-- ddl-end --

-- object: rds_replication | type: ROLE --
-- DROP ROLE IF EXISTS rds_replication;
CREATE ROLE rds_replication WITH
   INHERIT
   ENCRYPTED PASSWORD '********'
   ADMIN rds_superuser;
-- ddl-end --

-- object: rds_password | type: ROLE --
-- DROP ROLE IF EXISTS rds_password;
CREATE ROLE rds_password WITH
   INHERIT
   ENCRYPTED PASSWORD '********'
   ADMIN rds_superuser;
-- ddl-end --


-- Database creation must be done outside a multicommand file.
-- These commands were put in this file only as a convenience.
-- -- object: california_glaciers | type: DATABASE --
-- -- DROP DATABASE IF EXISTS california_glaciers;
-- CREATE DATABASE california_glaciers
--  ENCODING = 'UTF8'
--  LC_COLLATE = 'en_US.UTF-8'
--  LC_CTYPE = 'en_US.UTF-8'
--  TABLESPACE = pg_default
--  OWNER = cvanschoonhoven;
-- -- ddl-end --
--

-- -- object: public.geometry | type: TYPE --
-- -- DROP TYPE IF EXISTS public.geometry CASCADE;
```

```
-- CREATE TYPE public.geometry;
-- -- ddl-end --
--
-- object: postgis | type: EXTENSION --
-- DROP EXTENSION IF EXISTS postgis CASCADE;
CREATE EXTENSION postgis
WITH SCHEMA public
VERSION '2.5.2';
-- ddl-end --
COMMENT ON EXTENSION postgis IS E'PostGIS geometry, geography, and raster spatial
types and functions';
-- ddl-end --

-- object: public.ca_counties_gid_seq | type: SEQUENCE --
-- DROP SEQUENCE IF EXISTS public.ca_counties_gid_seq CASCADE;
CREATE SEQUENCE public.ca_counties_gid_seq
   INCREMENT BY 1
   MINVALUE 1
   MAXVALUE 2147483647
   START WITH 1
   CACHE 1
   NO CYCLE
   OWNED BY NONE;
-- ddl-end --
ALTER SEQUENCE public.ca_counties_gid_seq OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: public.ca_counties | type: TABLE --
-- DROP TABLE IF EXISTS public.ca_counties CASCADE;
CREATE TABLE public.ca_counties (
   gid integer NOT NULL DEFAULT nextval('public.ca_counties_gid_seq'::regclass),
   statefp character varying(2),
   countyfp character varying(3),
   countyns character varying(8),
   geoid character varying(5),
   name character varying(100),
   namelsad character varying(100),
   lsad character varying(2),
   classfp character varying(2),
   mtfcc character varying(5),
   csafp character varying(3),
   cbsafp character varying(5),
   metdivfp character varying(5),
   funcstat character varying(1),
   aland double precision,
   awater double precision,
```

```
   intptlat character varying(11),
   intptlon character varying(12),
   geom public.geometry,
   CONSTRAINT ca_counties_pkey PRIMARY KEY (gid),
   CONSTRAINT name UNIQUE (name)

);
-- ddl-end --
ALTER TABLE public.ca_counties OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: ca_counties_geom_idx | type: INDEX --
-- DROP INDEX IF EXISTS public.ca_counties_geom_idx CASCADE;
CREATE INDEX ca_counties_geom_idx ON public.ca_counties
   USING gist
   (
     geom
   )
   WITH (FILLFACTOR = 90);
-- ddl-end --

-- object: public.wbdhu6_gid_seq | type: SEQUENCE --
-- DROP SEQUENCE IF EXISTS public.wbdhu6_gid_seq CASCADE;
CREATE SEQUENCE public.wbdhu6_gid_seq
   INCREMENT BY 1
   MINVALUE 1
   MAXVALUE 2147483647
   START WITH 1
   CACHE 1
   NO CYCLE
   OWNED BY NONE;
-- ddl-end --
ALTER SEQUENCE public.wbdhu6_gid_seq OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: public.wbdhu6 | type: TABLE --
-- DROP TABLE IF EXISTS public.wbdhu6 CASCADE;
CREATE TABLE public.wbdhu6 (
   gid integer NOT NULL DEFAULT nextval('public.wbdhu6_gid_seq'::regclass),
   objectid bigint,
   tnmid character varying(40),
   metasource character varying(40),
   sourcedata character varying(100),
   sourceorig character varying(130),
   sourcefeat character varying(40),
   loaddate date,
```

```
    gnis_id bigint,
    areaacres numeric,
    areasqkm numeric,
    states character varying(50),
    huc6 character varying(6),
    name character varying(120),
    shape_leng numeric,
    shape_area numeric,
    geom public.geometry,
    CONSTRAINT wbdhu6_pkey PRIMARY KEY (gid),
    CONSTRAINT wbdhu6_name_key UNIQUE (name)

);
-- ddl-end --
ALTER TABLE public.wbdhu6 OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: wbdhu6_geom_idx | type: INDEX --
-- DROP INDEX IF EXISTS public.wbdhu6_geom_idx CASCADE;
CREATE INDEX wbdhu6_geom_idx ON public.wbdhu6
    USING gist
    (
      geom
    )
    WITH (FILLFACTOR = 90);
-- ddl-end --

-- object: public.glac_regions_gid_seq | type: SEQUENCE --
-- DROP SEQUENCE IF EXISTS public.glac_regions_gid_seq CASCADE;
CREATE SEQUENCE public.glac_regions_gid_seq
    INCREMENT BY 1
    MINVALUE 1
    MAXVALUE 2147483647
    START WITH 1
    CACHE 1
    NO CYCLE
    OWNED BY NONE;
-- ddl-end --
ALTER SEQUENCE public.glac_regions_gid_seq OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: public.glac_regions | type: TABLE --
-- DROP TABLE IF EXISTS public.glac_regions CASCADE;
CREATE TABLE public.glac_regions (
    gid integer NOT NULL DEFAULT nextval('public.glac_regions_gid_seq'::regclass),
    id integer,
```

```sql
    mtnregion character varying(50),
    geom public.geometry,
    CONSTRAINT glac_regions_pkey PRIMARY KEY (gid),
    CONSTRAINT mtnregion UNIQUE (mtnregion)

);
-- ddl-end --
ALTER TABLE public.glac_regions OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: glac_regions_geom_idx | type: INDEX --
-- DROP INDEX IF EXISTS public.glac_regions_geom_idx CASCADE;
CREATE INDEX glac_regions_geom_idx ON public.glac_regions
    USING gist
    (
      geom
    )
    WITH (FILLFACTOR = 90);
-- ddl-end --

-- object: public.ca_places_gid_seq | type: SEQUENCE --
-- DROP SEQUENCE IF EXISTS public.ca_places_gid_seq CASCADE;
CREATE SEQUENCE public.ca_places_gid_seq
    INCREMENT BY 1
    MINVALUE 1
    MAXVALUE 2147483647
    START WITH 1
    CACHE 1
    NO CYCLE
    OWNED BY NONE;
-- ddl-end --
ALTER SEQUENCE public.ca_places_gid_seq OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: public.ca_places | type: TABLE --
-- DROP TABLE IF EXISTS public.ca_places CASCADE;
CREATE TABLE public.ca_places (
    gid integer NOT NULL DEFAULT nextval('public.ca_places_gid_seq'::regclass),
    statefp character varying(2),
    placefp character varying(5),
    placens character varying(8),
    geoid character varying(7),
    name character varying(100),
    namelsad character varying(100),
    lsad character varying(2),
    classfp character varying(2),
```

```
    pcicbsa character varying(1),
    pcinecta character varying(1),
    mtfcc character varying(5),
    funcstat character varying(1),
    aland numeric,
    awater numeric,
    intptlat character varying(11),
    intptlon character varying(12),
    in_county character varying(254),
    geom_lengt numeric,
    geom_area numeric,
    geom public.geometry,
    CONSTRAINT ca_places_pkey PRIMARY KEY (gid)

);
-- ddl-end --
ALTER TABLE public.ca_places OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: ca_places_geom_idx | type: INDEX --
-- DROP INDEX IF EXISTS public.ca_places_geom_idx CASCADE;
CREATE INDEX ca_places_geom_idx ON public.ca_places
    USING gist
    (
      geom
    )
    WITH (FILLFACTOR = 90);
-- ddl-end --

-- object: public.people | type: TABLE --
-- DROP TABLE IF EXISTS public.people CASCADE;
CREATE TABLE public.people (
    contact_id integer NOT NULL,
    surname text,
    givennames text,
    prof_title text,
    affiliation text,
    department text,
    address1 text,
    address2 text,
    city text,
    state_province text,
    postal_code text,
    country_code character(2),
    office_loc text,
    url_primary text,
```

```
    url_secondary text,
    workphone_primary text,
    workphone_secondary text,
    workfax text,
    homephone text,
    mobilephone text,
    email_primary text,
    email_secondary text,
    comment text,
    CONSTRAINT people_pk PRIMARY KEY (contact_id)

);
-- ddl-end --
ALTER TABLE public.people OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: public.regional_center | type: TABLE --
-- DROP TABLE IF EXISTS public.regional_center CASCADE;
CREATE TABLE public.regional_center (
    rc_id integer NOT NULL,
    parent_rc integer,
    main_contact integer,
    url_primary text,
    url_secondary text,
    rc_poly polygon,
    CONSTRAINT "regional_Center_pk" PRIMARY KEY (rc_id),
    CONSTRAINT rc_id UNIQUE (rc_id)

);
-- ddl-end --
ALTER TABLE public.regional_center OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: public.submission_info | type: TABLE --
-- DROP TABLE IF EXISTS public.submission_info CASCADE;
CREATE TABLE public.submission_info (
    submission_id integer NOT NULL,
    submitter_id integer,
    rc_id integer,
    glac_region integer,
    file_name text,
    submission_time date,
    proc_desc text,
    source_scale text,
    coord_desc text,
    gid_glac_regions integer,
```

```
   CONSTRAINT data_source_gid_pk PRIMARY KEY (submission_id),
   CONSTRAINT submission_id UNIQUE (submission_id)

);
-- ddl-end --
ALTER TABLE public.submission_info OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: public.glaciers_static | type: TABLE --
-- DROP TABLE IF EXISTS public.glaciers_static CASCADE;
CREATE TABLE public.glaciers_static (
   glacier_id character varying(20) NOT NULL,
   glacier_name text,
   glims_id character varying(14),
   wgi_id character varying(20),
   rgi_id character varying(20),
   nhd_id character varying(40),
   gnis_id character varying(10),
   recno character varying(3),
   parent_icemass_id character varying(20),
   glac_status smallint NOT NULL DEFAULT 0,
   CONSTRAINT glaciers_static_pk PRIMARY KEY (glacier_id),
   CONSTRAINT glaciers_static_glacier_id_key UNIQUE (glacier_id)

);
-- ddl-end --
ALTER TABLE public.glaciers_static OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: public.glaciers_variable | type: TABLE --
-- DROP TABLE IF EXISTS public.glaciers_variable CASCADE;
CREATE TABLE public.glaciers_variable (
   glacier_id character varying(20),
   submission_id integer NOT NULL,
   glac_name character varying(28),
   area numeric,
   db_area numeric,
   perimeter numeric,
   min_elev numeric,
   max_elev numeric,
   mean_elev numeric,
   glacial_region character varying(20),
   in_county text,
   in_basin text,
   num_basins smallint,
   fcode integer DEFAULT 37800,
```

```
    date timestamp,
    geom public.geometry,
    max_width numeric,
    max_length numeric,
    slope smallint,
    aspect smallint,
    connect smallint,
    surging smallint,
    linkages smallint,
    form smallint,
    term_type smallint,
    x_coord numeric,
    y_coord numeric,
    loc_unc_x smallint,
    loc_unc_y smallint,
    glob_unc_x smallint,
    glob_unc_y smallint,
    prime_class smallint,
    frontal_char smallint,
    long_char smallint,
    tongue_act smallint,
    moraines1 smallint,
    moraines2 smallint,
    source_nourish smallint,
    min_elev_exp smallint,
    mean_elev_acy smallint,
    mean_elev_abl smallint,
    activity_start smallint,
    activity_end smallint,
    snowline_acy smallint,
    snowline_date smallint,
    mean_depth smallint,
    deapth_acy smallint,
    area_acy smallint,
    area_exp smallint,
    mean_width smallint,
    mean_length smallint,
    max_len_ex smallint,
    max_len_ab smallint,
    orient_acc text,
    orient_abl text,
    remarks text,
    CONSTRAINT glims_polygons_pkey PRIMARY KEY (submission_id)

);
-- ddl-end --
```

```
ALTER TABLE public.glaciers_variable OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: public.attachments | type: TABLE --
-- DROP TABLE IF EXISTS public.attachments CASCADE;
CREATE TABLE public.attachments (
   attach_name text NOT NULL,
   glacier_id character varying(20),
   file_type character varying(4),
   "URL" text,
   adate date,
   editor text,
   author text,
   description text,
   submission_id_glaciers_variable integer,
   CONSTRAINT attachments_pk PRIMARY KEY (attach_name)

);
-- ddl-end --
COMMENT ON COLUMN public.attachments.adate IS 'data of publication';
-- ddl-end --
ALTER TABLE public.attachments OWNER TO cvanschoonhoven;
-- ddl-end --

-- object: glaciers_variable_fk | type: CONSTRAINT --
-- ALTER TABLE public.attachments DROP CONSTRAINT IF EXISTS glaciers_variable_fk
CASCADE;
ALTER TABLE public.attachments ADD CONSTRAINT glaciers_variable_fk FOREIGN
KEY (submission_id_glaciers_variable)
REFERENCES public.glaciers_variable (submission_id) MATCH FULL
ON DELETE SET NULL ON UPDATE CASCADE;
-- ddl-end --

-- object: glac_regions_fk | type: CONSTRAINT --
-- ALTER TABLE public.submission_info DROP CONSTRAINT IF EXISTS glac_regions_fk
CASCADE;
ALTER TABLE public.submission_info ADD CONSTRAINT glac_regions_fk FOREIGN
KEY (gid_glac_regions)
REFERENCES public.glac_regions (gid) MATCH FULL
ON DELETE SET NULL ON UPDATE CASCADE;
-- ddl-end --

-- object: in_county | type: CONSTRAINT --
-- ALTER TABLE public.ca_places DROP CONSTRAINT IF EXISTS in_county CASCADE;
ALTER TABLE public.ca_places ADD CONSTRAINT in_county FOREIGN KEY
(in_county)
```

**REFERENCES public.**ca_counties **(**name**) MATCH** SIMPLE
**ON DELETE NO** ACTION **ON UPDATE NO** ACTION**;**
-- ddl-end --

-- object: parent_rc | type: CONSTRAINT --
-- ALTER TABLE public.regional_center DROP CONSTRAINT IF EXISTS parent_rc CASCADE;
**ALTER TABLE public.**regional_center **ADD CONSTRAINT** parent_rc **FOREIGN KEY (**parent_rc**)**
**REFERENCES public.**regional_center **(**rc_id**) MATCH** SIMPLE
**ON DELETE NO** ACTION **ON UPDATE NO** ACTION**;**
-- ddl-end --

-- object: rc_id | type: CONSTRAINT --
-- ALTER TABLE public.submission_info DROP CONSTRAINT IF EXISTS rc_id CASCADE;
**ALTER TABLE public.**submission_info **ADD CONSTRAINT** rc_id **FOREIGN KEY (**rc_id**)**
**REFERENCES public.**regional_center **(**rc_id**) MATCH** SIMPLE
**ON DELETE NO** ACTION **ON UPDATE NO** ACTION**;**
-- ddl-end --

-- object: submitter_id | type: CONSTRAINT --
-- ALTER TABLE public.submission_info DROP CONSTRAINT IF EXISTS submitter_id CASCADE;
**ALTER TABLE public.**submission_info **ADD CONSTRAINT** submitter_id **FOREIGN KEY (**submitter_id**)**
**REFERENCES public.**people **(**contact_id**) MATCH** SIMPLE
**ON DELETE NO** ACTION **ON UPDATE NO** ACTION**;**
-- ddl-end --

-- object: in_county | type: CONSTRAINT --
-- ALTER TABLE public.glaciers_variable DROP CONSTRAINT IF EXISTS in_county CASCADE;
**ALTER TABLE public.**glaciers_variable **ADD CONSTRAINT** in_county **FOREIGN KEY (**in_county**)**
**REFERENCES public.**ca_counties **(**name**) MATCH** SIMPLE
**ON DELETE NO** ACTION **ON UPDATE NO** ACTION**;**
-- ddl-end --

-- object: in_basin | type: CONSTRAINT --
-- ALTER TABLE public.glaciers_variable DROP CONSTRAINT IF EXISTS in_basin CASCADE;
**ALTER TABLE public.**glaciers_variable **ADD CONSTRAINT** in_basin **FOREIGN KEY (**in_basin**)**
**REFERENCES public.**wbdhu6 **(**name**) MATCH** SIMPLE
**ON DELETE NO** ACTION **ON UPDATE NO** ACTION**;**
-- ddl-end --

-- object: glacial_region | type: CONSTRAINT --
-- ALTER TABLE public.glaciers_variable DROP CONSTRAINT IF EXISTS glacial_region CASCADE;
**ALTER TABLE public.**glaciers_variable **ADD CONSTRAINT** glacial_region **FOREIGN KEY (**glacial_region**)**
**REFERENCES public.**glac_regions **(**mtnregion**) MATCH** SIMPLE
**ON DELETE NO** ACTION **ON UPDATE NO** ACTION**;**
-- ddl-end --

-- object: submission_id | type: CONSTRAINT --
-- ALTER TABLE public.glaciers_variable DROP CONSTRAINT IF EXISTS submission_id CASCADE;
**ALTER TABLE public.**glaciers_variable **ADD CONSTRAINT** submission_id **FOREIGN KEY (**submission_id**)**
**REFERENCES public.**submission_info **(**submission_id**) MATCH** SIMPLE
**ON DELETE NO** ACTION **ON UPDATE NO** ACTION**;**
-- ddl-end --

-- object: glaciers_variable_glacier_id_fkey | type: CONSTRAINT --
-- ALTER TABLE public.glaciers_variable DROP CONSTRAINT IF EXISTS glaciers_variable_glacier_id_fkey CASCADE;
**ALTER TABLE public.**glaciers_variable **ADD CONSTRAINT** glaciers_variable_glacier_id_fkey **FOREIGN KEY (**glacier_id**)**
**REFERENCES public.**glaciers_static **(**glacier_id**) MATCH** SIMPLE
**ON DELETE NO** ACTION **ON UPDATE NO** ACTION**;**
-- ddl-end --

-- -- object: public.geometry | type: TYPE --
-- -- DROP TYPE IF EXISTS public.geometry CASCADE;
-- CREATE TYPE public.geometry;
-- -- ddl-end --
--