Predicting Floods by Visualizing and Analyzing Latest Weather Data

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Key words: Geoinformation, Risk management, HTML5, Time-aware data, Disaster prediction/recovery

SUMMARY

In June 2013, heavy rainfall in the Canadian Rockies and foothills triggered the worst floods in the history of Alberta. Many communities were displaced and downtown Calgary was completely shut down for days. Sadly, five people perished and property damage amounted to over five billion dollars. The government agency in charge of monitoring the province's rivers water level is the River Forecast Centre (RFC) from the ministry of Environment and Parks of Alberta. In case of an emergency, RFC will act as expert support to several groups such as dam operators, emergency operation centres, industry, First Nations and the general public.

In the past, RFC was limited in their rainfall accumulations analysis. Better tools to automate and enhance the visualization and analysis processes were needed to provide better flood forecasts based on watershed basins. To address their needs, a new GIS web application named the Weather Model Assessment Tool (WMAT) was developed. This tool enabled RFC employees to visualize and animate several weather data models and select at-risk watershed basins for detailed analysis.

The base data ingested by this new application is downloaded several times each day from the Environment Canada website. The downloaded data is then processed and incorporated in the WMAT website seamlessly. RFC employees can choose a weather model and see the animated precipitation forecast over time. They can also select a basin for further analysis. Then, an Open Source JavaScript tool generates a chart of the amount of precipitation over time. Additionally, WMAT prepares data text files for another RFC's flow forecast tool.

The project was under strict time and budget constraints, therefore an agile development process had to be used to get the best out of the available technology in a sustainable and efficient manner.

WMAT is a key application which transcends levels of government and conveys critical information to assist the prediction of floods and recover from them. The ability to animate and analyze the daily models enables RFC to produce defensible flow forecasts and undertake any actions that will protect Albertan lives and properties.

SUMMARY (French)

En juin 2013, de fortes pluies dans les Rocheuses canadiennes et leurs contreforts ont déclenché les pires inondations de l'histoire de l'Alberta. De nombreuses communautés ont été déplacées et le centre-ville de Calgary a été complètement fermé pendant quelques jours. Malheureusement, cinq personnes ont péri et les dommages matériels se chiffrent à plus de cinq milliards de dollars. L'organisme responsable de la surveillance du niveau de l'eau des rivières de la province est le River Forecast Centre (RFC). Cette entité fait partie du ministère de l'Environnement et des Parcs de l'Alberta. Dans le cas d'un risque d'inondation, le rôle du RFC est de supporter les opérations de mitigation en collaboration avec plusieurs groupes tels que les opérateurs de barrages, les centres d'opérations d'urgence, l'industrie, les Premières Nations et le grand public.

Dans le passé, le RFC était limité dans ses analyses des accumulations de pluie. De meilleurs outils pour automatiser et améliorer les processus de visualisation et d'analyse étaient nécessaires pour fournir des prévisions des crues de meilleure qualité en tenant compte des bassins versants. Pour répondre à leurs besoins, nous avons développé une nouvelle application SIG web nommé Weather Model Assessment Tool (WMAT). Cet outil a permis aux employés du RFC de visualiser les prédictions météorologiques facilement et de sélectionner les bassins à risque de crues pour une analyse détaillée.

Les données de base de l'application sont téléchargées plusieurs fois par jour à partir du site Web d'Environnement Canada. Celles-ci sont ensuite traitées, puis intégrées dans l'outil WMAT. Les employés du RFC sont maintenant en mesure de choisir un modèle météorologique et d'animer la couche de précipitations selon le temps. Ils peuvent également sélectionner un bassin versant à risque pour une analyse plus poussée. Un outil Open Source JavaScript sert à générer un graphique sur la quantité de précipitations selon le temps pour le bassin sélectionné. De plus, WMAT génère aussi des fichiers textes qui sont utilisés dans un autre outil de prévision de débits des rivières du RFC.

Le projet était réalisé sous des contraintes serrées de temps et de budget, donc un processus de développement agile a été mis en place afin de tirer le maximum de la technologie en place.

WMAT est une application clé qui transcende les niveaux de gouvernement et permet le transfert d'information critique pour la prédiction des inondations. La capacité à animer et à analyser les prédictions quotidiennes permet au RFC de produire des prévisions robustes du débit des cours d'eau et de prendre les mesures nécessaires pour protéger la vie des Albertains et leur propriété.

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1. CONTEXT

1.1 Calgary 2013 Floods

In June 2013, heavy rainfall in the Canadian Rockies and foothills triggered the worst floods in the history of Alberta (Figure 1). Many major rivers in Southern Alberta saw their normal flow multiplied up to ten times their normal rate (Francey, 2013). Sadly, five people perished during these floods and the total cost sums up to over five billion Canadian dollars (Calgary Herald, 2014). Thirty communities and around a hundred thousand people were affected by the floods (Canadian Broadcasting Corporation, 2014).

Calgary, the largest city in Alberta, saw its downtown area flooded by the Bow River and remain virtually shut down for several days. Animals from the Calgary Zoo even needed to be evacuated since it is located on the shores of the river. Giraffes walked in water belly-deep and the big cats were moved to the police station's cells (Calgary Herald, 2013).

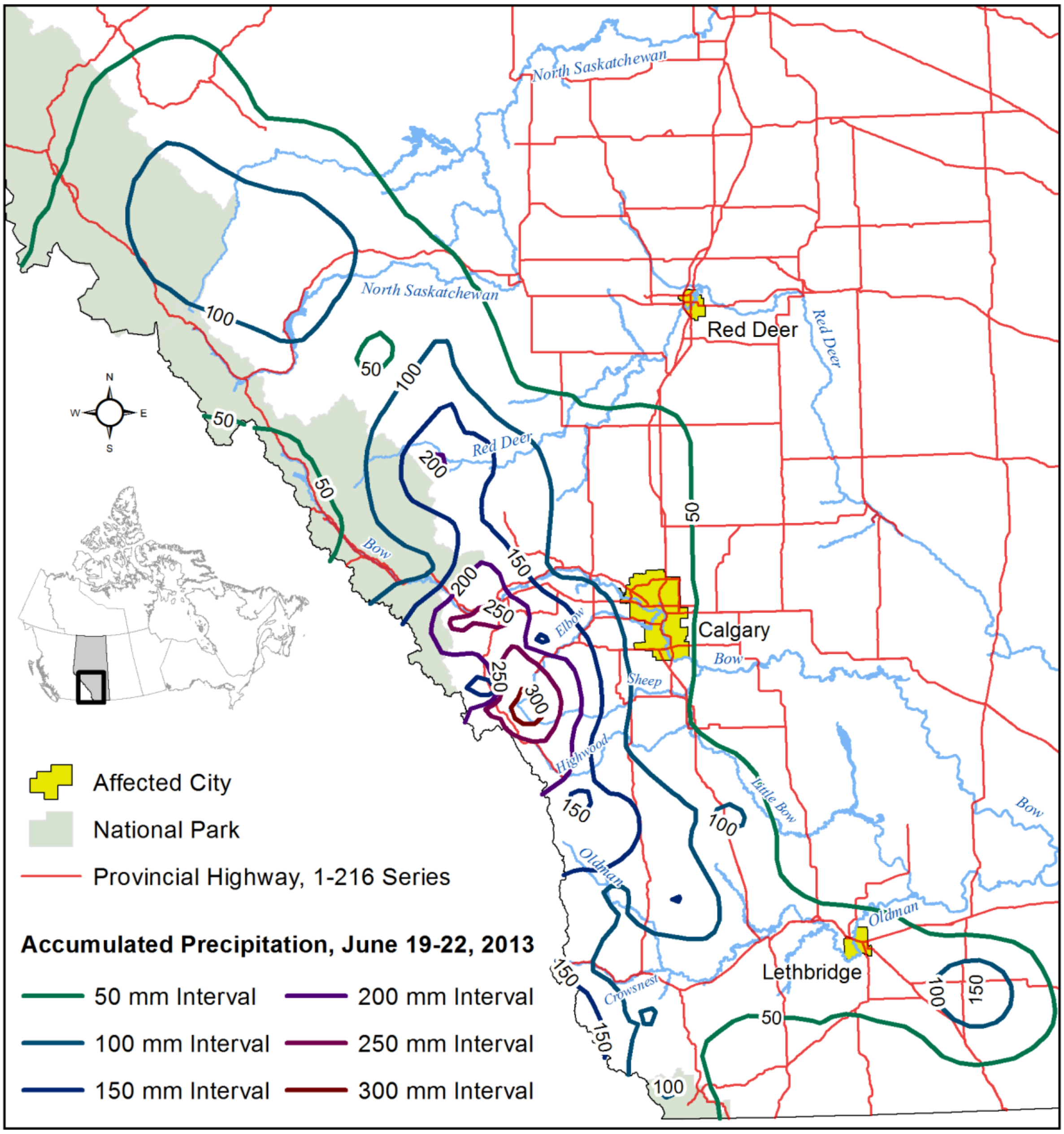

Figure 1 - Accumulated precipitation, June 19-22, 2013. (Hwy43, 2013)

1.2 Weather Pattern in Southern Alberta

There is a normal weather pattern that usually brings a lot of rain and thunderstorms in Southern Alberta at the end of June. Three factors are causing this pattern (Larkins, 2014):

1. The Jet Stream is a fast wind current that flows from West to East. In the summer, it moves northward above Canada, bringing moist air from the Pacific in its midst;

2. The Canadian Rockies topography, with their large elevation difference, is contributing to the creation of thunderstorms;

3. High temperatures during the hot summer days make ground water evaporate and form clouds.

So what was different in 2013? Unusual conditions were united to create massive rainfalls and the ensuing floods. First, a heavily water-packed low pressure system hit Southern Alberta. This is not unusual and would have normally passed by, but not this time. It was blocked to the West by the mountains, to the East by wind currents blowing westerly and to the North by a high-pressure system. In these conditions, the rain heavily poured down locally for an extended period of time. This caused mountain snow to melt, which added to the amount of water accumulating. The shallow, still frozen ground was soaked up quickly and couldn't absorb this flood, which descended quickly east, following the rivers towards inhabited areas (Davison & Powers, 2013).

1.3 Response and Recovery

Immediate response from municipal, provincial and federal government included intervention from the Canadian forces, coordination of the rescue efforts and urgent repairs and distribution of preloaded debit cards to supply basic goods to the evacuees (Alberta Government, 2014). Let's not forget thousands of volunteers and professionals who offered their assistance through and after the crisis.

After this natural disaster, medium and long-term mitigation actions were planned by the Albertan Government (Alberta Government, 2014). These include:

- Higher construction standards for highways and bridge structures, schools, hospitals and provincial buildings. Existing structures would be upgraded to better resist floods;
- Better mapping and understanding of flooding risks;
- Upgrade of critical water management infrastructures;
- Funds to support homeowners who wish to relocate from the floodway;
- Ban on new developments in floodways.

2. ENHANCING FLOOD PREDICTION

2.1 River Forecast Center

Alberta Environment and Park's ministry is home for the River Forecast Centre (RFC). This governmental entity serves multiple functions such as:

- *Providing flood warnings for river flood events due to melting snow or heavy rainfall;*

- *Producing monthly water supply forecasts from February to August and providing day-to-day water supply forecasting services during periods of low flow;*

- *Responding to information requests from the public which are on the increase as interest in river-related recreation grows; and*

- *Developing reservoir operation procedures for flood and water supply management.*

(Environment Canada, 2014)

Following the 2013 floods, projects and discussions with the academic community and Environment Canada were put in place to enhance floods detection mechanisms. It was determined that the River Forecast Centre (RFC) would supplement the current method of using local forecasts as provided by meteorologists by implementing a wider watershed basins analysis. Using Environment Canada gridded suite of models would allow the RFC to prepare probabilistic forecasts for clients (dam operators, municipal emergency managers, industry, First Nations and the general public). Environment Canada provides up-to-date snow and rainfall forecasts several times a day in freely downloadable GRIB2 files. This file format is used to store gridded meteorological data. Before the development of our tool, those files were downloaded manually by the RFC to be ingested in their forecast system. They needed a way to automate this process and to visually display these data within a web viewer. Our team answered their need by developing an innovative solution called the Weather Model Assessment Tool (WMAT).

2.2 Requirements

The requirements of the WMAT were the following:

- Download up-to-date GRIB2 files from Environment Canada website several times a day to cover all the models, themes and forecast time. See section 3.2.1 for a comprehensive table;

- Provide a viewer to animate and visualize the weather forecast models and the water-basins;

- Perform per-basin forecast analysis charts on demand;

- Generate downloadable CSV and WISKI text files of the weather forecast statistics for on-demand basins;

- Previous seven days of data should be available to visualize and download.

3. WEATHER MODEL ASSESSMENT TOOL (WMAT)

3.1 Final Product: WMAT Web Viewer

The final product is shown at this point to better illustrate the technological components in the next sub-sections.

WMAT is a web application accessible in all the major browsers. It is secured and available only to several Alberta Environment and Parks employees. It is coded in HTML5 (HTML + JavaScript + CSS), so no web-plugin is required. Figure 2 shows the final web application.

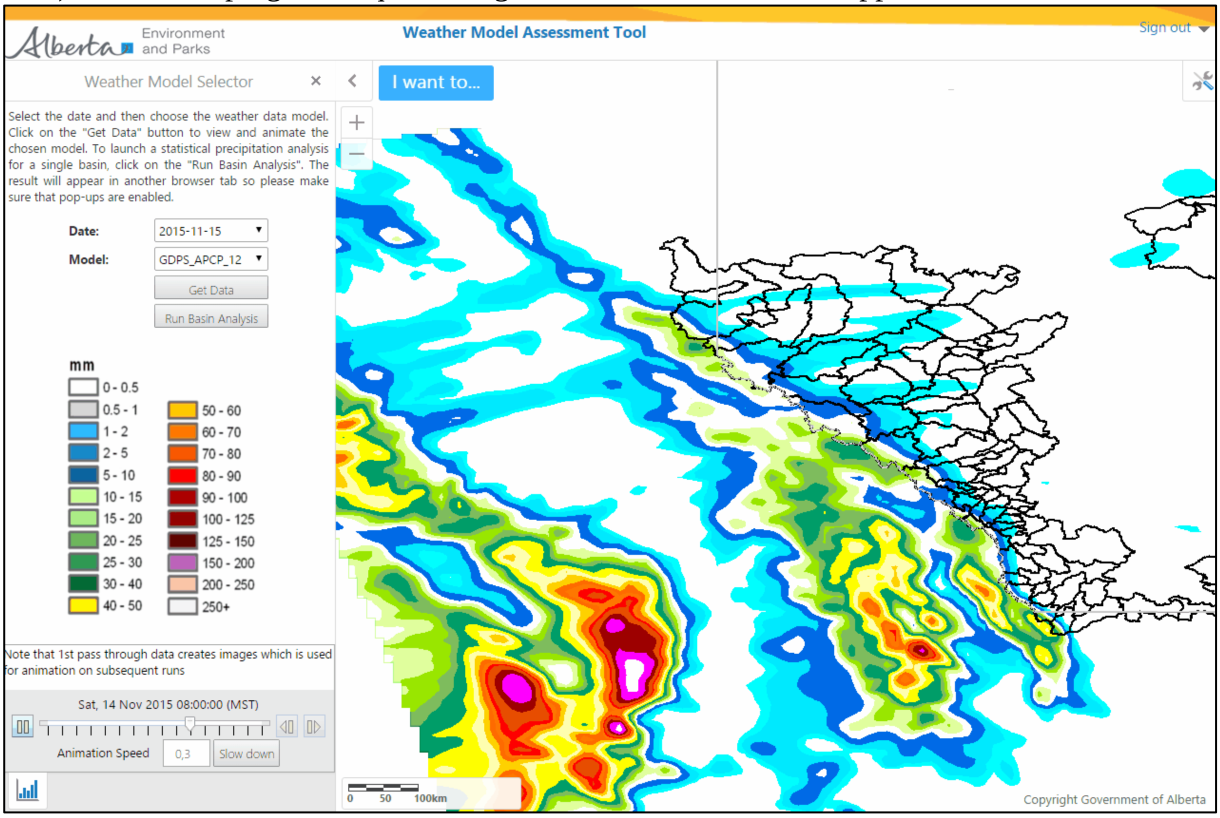

Figure 2 - The Weather Model Assessment Tool (WMAT) Web Viewer

The first step is to select a date in the control on the left panel. The user can select any date between six days ago and today. Next, the user chooses the forecast model, the theme, and the forecast time and hits *Get Data*. As shown in Figure 2, once a model is chosen, the legend appears and the time slider at the bottom right is enabled. Then, the user clicks on the play button to animate the forecast in the fashion of weather newscast seen on television.

To run a specific basin analysis, the user clicks on Run Basin Analysis and then on a water-basin on the map. That action triggers a geoprocessing service that calculates precipitation accumulation statistics over time (Figure 3). On that webpage, a chart is drawn from the calculated statistics and a CSV and a WISKI files are generated and ready to be downloaded.

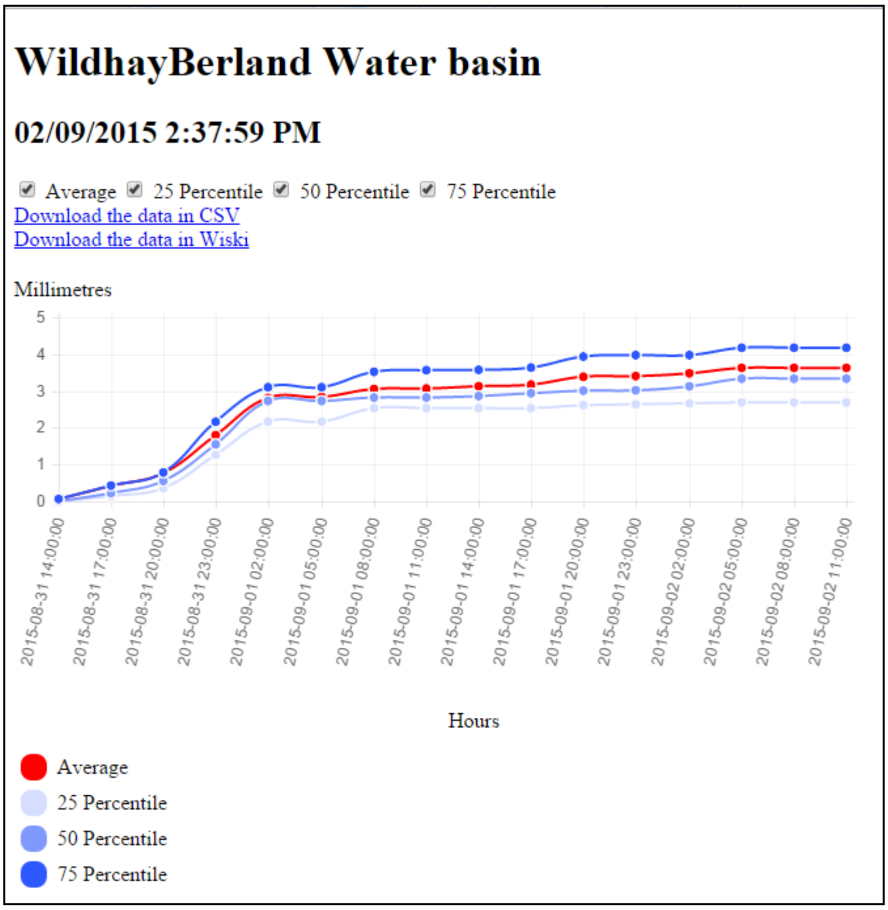

Figure 3 - Watershed basin analysis and downloadable data files

3.2 Technologies

3.2.1 Data

Concerning the forecast file formats, ArcGIS offers more support and flexibility to publish and calculate statistics using NetCDF format than GRIB2. Similar to GRIB2, NetCDF is a self-describing format that supports scientific gridded data. In order to convert GRIB2 files downloaded from the Environment Canada website into NetCDF, a utility called WGRIB-2 was used. It is freely available and distributed by the United States National Oceanic and Atmospheric Administration (NOAA) (National Weather Service, Climate Prediction Center, 2015).

Figure 4 illustrates all the GRIB2 files to be downloaded from the Environment Canada website for a single day to answers the initial requirements. There are four forecast models (see Environment Canada website for full details):

- HRDPS: High Resolution Deterministic Prediction System;
- RDPS: Regional Deterministic Prediction System;

- GDPS: Global Deterministic Prediction System;
- NAEFS: North American Ensemble Forecast System.

Two themes can be available depending on the model:

- Snow Depth (SNOD);
- Accumulated Precipitation over time (APCP).

All these forecasts are recalculated several times per day. HRDPS and RDPS are recalculated four times per day and twice for GDPS and NAEF. A total of twenty files are downloaded daily (Figure 4).

Product	Theme	Grid	Interval Hours	Forecast Run Time (hours)	Forecast Launch Time
HRDPS	Snow Depth Accumulated Precipitation	2.5 KM	1	48	00:00 06:00 12:00 18:00
RDPS	Snow Depth Accumulated Precipitation	10 KM	1	48	00:00 06:00 12:00 18:00
GDPS	Accumulated Precipitation	25 KM	3	240	0:00 12:00
NAEF (Ensemble)	Accumulated Precipitation	Lat-Lon	6	384	0:00 12:00

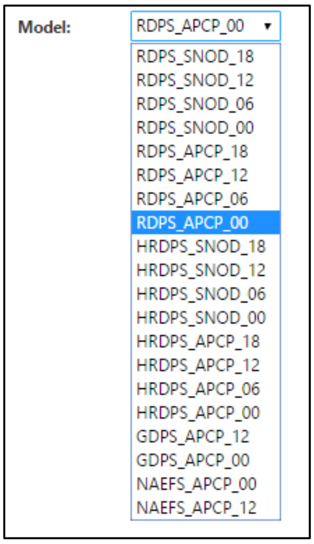

Figure 4 - Data needed for a single day and the resulting control in the web viewer

3.2.2 Client–Side Technologies

At Alberta Environment and Park, the majority of web map viewers are managed using the Geocortex solution. This framework, which is built upon ESRI products, enables quick configuration and publishing of Silverlight or HTML5 web map viewers. At the beginning of the project, the Silverlight version of the Geocortex viewer was more advanced than its HTML5 counterpart. It included more tools, such as a time slider which is used to animate time-enabled layers. Nevertheless, we decided to publish an HTML5 site because we knew that Silverlight would not be supported in the long run by the major browsers. Also, we were able to animate the time-enabled forecast layers using the underlying ArcGIS API for JavaScript, which was the most critical part of the project.

The chart in the analysis web page is generated using a lightweight open source HTML5 tool called Chart.js (chartjs.org) (Figure 3). It was simple to put in place and delivers a neat esthetic to show the statistics.

3.2.3 Server–Side Technologies

Publishing time-enabled forecast layers was a challenge because the underlying data changes daily. Also, Geocortex viewers require a static URL to the map services displayed on the map. The solution was to create and publish a MXD with 140 map services (7 days x 20 models) relying on NetCDF files stored on the server. These map services have a static URL that won't change because they have a standard name: Folder/Model_Theme_LaunchTime (ex.: Today_01/RDPS_SNOD_18). The number in the folder name is the number of days from today (ex.: Today_00 is today, Today_01 is yesterday, Today_02 is the day before yesterday and so on until Today_06). Every night, the folders are swapped: Today_00 becomes Today_01, Today_01 becomes Today_02, and so on. A new folder called Today_00 is created and the old Today_06 is deleted to keep seven days of data. The NetCDF files are added in the Today_00 folder as the data becomes available to download during the current day.

When the user triggers analysis on a specific watershed basin, a geoprocessing service coded in Python on the server calculates accumulated precipitation statistics (mean, 25, 50 and 75 percentiles) and generates the web page as seen on Figure 3.

The three images below illustrate the percentiles and mean calculations. Figure 5 shows the watershed to be analyzed and the forecasted accumulated precipitation.

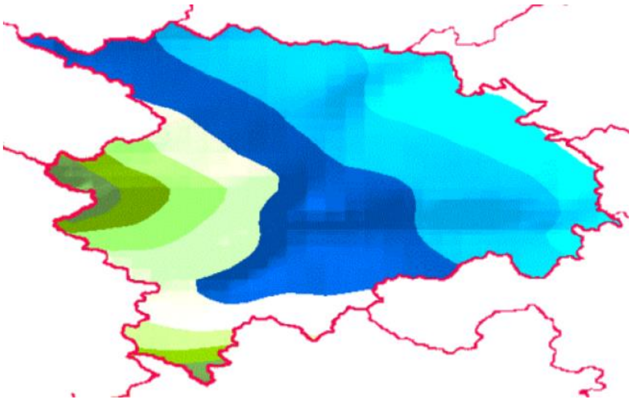

Figure 5 - Watershed basin and coloured forecast model

The ArcGIS tool named *Extract by mask* is used to extract all the forecast cells that intersect the basin polygon. The cell size is set as small as possible to describe the basin in the most accurate way possible. Figure 6 shows bigger cells to illustrate the algorithm.

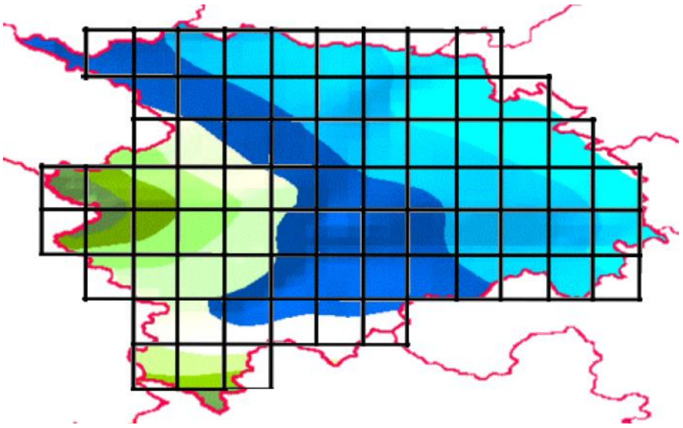

Figure 6 - A grid is extracted by the polygonal mask

Figure 7 shows the final extracted cells. The accumulated precipitation values, represented by a colour code, are then put into an ascending array.

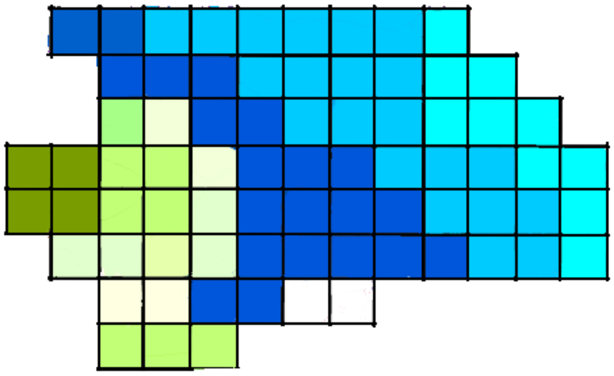

Figure 7 - Forecast grid ready to be analyzed

Using Figure 7, the resulting array would contain 75 items for which we are easily able to calculate the mean value and the 25, 50 and 75 percentiles. The percentile value (n^{th} item in the array) is calculated using the equation below where P is the percentile (in our case 25, 50 or 75) and N the number of items in the list.

$$n = \left\lceil \frac{P}{100} \, x \, N \right\rceil$$

3.3 Methodology

The project was under strict time and budget constraints, therefore an agile development process had to be put in place to get the best out of the available technologies in a sustainable and efficient manner. We held a quick meeting every day with the development team and the client was involved in each step of the process to ensure that we deliver exactly what RFC wanted. Several points in the initial architecture solutions were not clearly defined at the start. Therefore, we developed several proofs of concept to validate the grey areas of our architecture. For instance, we put in place a simple JavaScript viewer to see how to animate a layer. With our architecture now validated, we built upon our proofs of concepts to deliver the final product.

4. CONCLUSION

Century floods in Southern Alberta are inevitable. Since 2013, considerable work has been done to limit the potential damages the next flood could cause. The WMAT falls into the global mitigation plan to get the right tools in the hands of knowledgeable professionals. The project was able to deal successfully with many complex aspects of GIS such as time-aware layers, base data that changes daily and raster analysis. By enabling the visualization of animated forecasts and the generation of rain precipitation statistics, RFC employees are now able to obtain a watershed wide view of rainfall accumulations (spatially and temporally) as they prepare the inputs to their river forecast models. We are confident that our tool will prove useful in case of a major flood and help save lives and properties.

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BIOGRAPHICAL NOTES

Vincent Thomas has a Master’s degree from Laval University in GIS sciences and he has been working for Fujitsu since 2011. He delivered several projects successfully in the fields of transportation, environment and agriculture. He is also interested in 3D modeling, mobility and augmented reality applications.

Felix Friedmann is a Business Intelligence Specialist with over 35 years' experience in the computing field. He has worked extensively in the Business Intelligence realm in for over 13 years and is familiar with all its major technologies. In the last 3 years Felix has branched out into the GIS projects as a Business Analyst. In that capacity he has worked on one of the largest ArcGIS applications in Alberta, Canada.

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