The potential impacts of climate change on water supply and hydropower in St. Vincent

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Abstract

It is now widely accepted that small island states (SIDS) are expected to be severely impacted by climate change. One of the most important responses to adverse impacts relates to adaptation measures to the current high costs of energy and the expansion of renewable energy. St. Vincent and the Grenadines is one of the few small islands where hydropower potential exists and has been harnessed. Hydropower production is based on, and limited by, the available water resources, which are in turn affected by the hydrological cycle. Annual and seasonal streamflow variability are the main consequences of climate change that can affect the generation of electricity by hydro plants and are determinants in the ability of St. Vincent and the Grenadines to continue harnessing the hydropower potential. Consequently, climate change should be taken into consideration when planning new or in operating existing hydropower plants.

This paper analysed the effects of climate change on the water supply from the Cumberland watershed in St. Vincent. Using available hydrological data, a Rainfall-Runoff model, HEC-HMS, was applied. For future hydrologic conditions, for various climate change scenarios and the associated projected meteorological inputs were inputted into to evaluate the potential impacts on water supply and hydropower production annual flows were projected to decrease by 8% to about 25% over the next 80 years. The simulated results also showed that by 2090 there can be a decrease of 25% hydropower production for the high emission scenario and compared to 11.5% for the low emission scenario.

1. Introduction

It is now widely accepted that St. Vincent and the Grenadines (SVG) and other small island states (SIDS) would be severely impacted by climate change. It is expected to impact all sectors within the Caribbean with the anticipated onset of impacts varying from locality to locality (Farrell, Nurse and Mosely, 2008). Changing climate can and does have an impact on catchment hydrology and that impact may be negative. Contemporary climate changes would result in changes climate variables: air temperature, precipitation, annual and seasonal runoff, frequency of different water year types (dry normal and wet), and intensity of low-flow periods relative to current conditions. In SVG average precipitation has shown a decline of around 8.2mm per month (-5.7%) per decade over the period 1960-2006 (Mc Sweeney, New and Lizcano, 2008). The impact of continued decline is likely to be felt the greatest on water resources for water supply, agriculture and hydropower. The current pressures on water resources due to the increasing water and energy demand and shrinking water supplies are likely to be exacerbated by climate change.

In SIDS there is generally no real potential for hydropower due to limited water resources. However in a few islands, like the Fiji hydropower which existed for decades have expanded from projects over the last 10 years (IRENA 2014). In SVG the hydropower potential has not yet been fully utilised. Although some studies of the island’s untapped hydro potential have been conducted, no firm steps have been taken to construct additional plants (GOSVG 2000). In 2009, the St. Vincent Electricity Services Limited (Vinlec) undertook a study into the rehabilitation of the Richmond Hydropower Plant and the rehabilitation and expansion of South Rivers Hydropower Plant which promoted refurbishment projects at both plants (Vinlec, 2015). Currently,
one-quarter of the 20 megawatts of electricity generated during peak demand in St. Vincent and the Grenadines comes from the country’s three hydropower plants. The remaining 15 megawatts is generated by 70 million dollars of imported diesel in 2013. While the relative quantity of hydropower in the overall power generation have decreased from 47% in 1990 to about 27% in 1997 (GOSVG 2000) and by a further 2% by 2013, its importance as a renewable energy would continue. Hydropower generation has decreased, partly because of water constraints (GOSVG 2000). The local authority has recognised that any significant decrease in precipitation will severely affect development in SVG as the loss of hydropower-generating capacity will result in decreased productivity or greater reliance on diesel power which would ultimately reduce SVG’s ability to meet its emission reduction obligations (GOSVG 2000).

While it cannot be known precisely what the climate scenario, a century from now, would be it is clear that hydropower has a major role to play in delivering clean and sustainable energy to the growing Vincentian population. It is also equally clear that if hydropower is to continue to be a key energy source for SVG, the impact of changing water flows must be considered extremely carefully and far into the future as possible. The drought of 2010 can be used as an indicator on how hydropower generation can be affected in the future. In the first month of 2008, 2009 and 2010 hydropower contributed 17.3%, 28.12% and 8.17% respectively, while in the second month of 2008, 2009 and 2010 it contributed 21.12%, 28.69% and 12.01% respectively (Trotman, 2013).

Reduction in hydropower generation increases the use of diesel which raises the price that consumers pay for electricity. Overall, there is, therefore the need for planning which requires an understanding of future potential impacts of climate change on water resources and hydropower.

Despite the importance of hydropower production in SVG and its potential sensitivity to climate change and the competition for water between domestic water supply systems and hydropower production, little research has been carried to address these issues. Such research are critical to managing the risks that climate change poses to water-related investment projects by identifying appropriate options, guidelines, and methodologies for adaptation. The analysis of intermediate climate change scenarios can help determine potentially critical situations due to possible decrease in stream flows and how such situations may drive the competition between supply and hydropower. This paper analyses the effects of climate change on the water supply from the Cumberland watershed in St. Vincent. Using available hydrological data, a Rainfall-Runoff model, HEC-HMS, was applied to the Cumberland Catchment. The hydrological model output is used to determine the future streamflow in the watershed for various climate change scenarios and the potential hydropower production.

2. Literature review

Given the large-spatial and temporal scales of projections from Global Climate Models (GCMs), downscaling of climate variables from Global Climate Models (GCMs) are applied to better understand the potential variability of climate in small island regions like the Caribbean. Earlier application of GCM-based rainfall projections for the region suggest slight decline in annual rainfall, a slight increases in December–February
rainfall, decreases in June–August rainfall, a decrease in annual rainy days (Nurse and Sem, 2001).

Most of the research to date in the English speaking Caribbean has utilized Providing REgional Climates for Impact Studies (PRECIS) for simulating future climate variability. Recent results using (PRECIS) for the period 2071–2100 suggests that the annual rainfall is projected to increase north of 22 N and decrease (~25–50%) south of this latitude (Campbell 2011). One of the weaknesses of the regional models is that while the annual cycle of temperature and rainfall is well simulated they are not able to capture the inter-annual variability (Syed, et al. 2014).

Cognizant of the uncertainties, climate modeling for the Caribbean shows that total annual precipitation has declined in in recent years models project stronger declines in the future, particularly under higher emission scenarios. Such decreases do not only threaten island communities that rely on rainfall for replenishing their freshwater supplies but also on existing and potential hydropower generation in a few of the islands where it is possible.

In the past decade, growing concern about the climate impacts of greenhouse gas emissions has prompted many governments to adopt policies in favour of low-carbon-energy sources (Pittock et al., 2008). The hydropower industry seized its position at the top of the renewable energy sector and secured substantial resources through the Kyoto Clean Development Mechanism. Hydropower is electricity generated by the force of moving water and is considered a renewable source of energy, as it relies on water which is continuously renewed through the natural water cycle. It accounts for about 17 percent of the world’s total electricity generation (U.S. Energy Information Administration 2008). It is an important technology for balancing out other renewable energies and also in aiding climate change adaptation.

There are large variations of changes (increases/decreases) in hydropower generation across regions and even within regions (Hamududu and Killingtveit, 2012). In order for hydropower schemes to function, in the future, as designed, and provide social and economic benefits, the impacts of climate change need to be taken into account. How climate change affects hydropower depends on the type of system in use. Generally, an increase in amount of annual river discharge can sometimes simply translate to an increase in hydropower production. However, fluctuations in discharge affect different types of facilities differently. Run-of-river dams, for example, may be more vulnerable to decreased amounts of discharge because they are directly dependent on the river’s flow, whereas reservoir dams may be able to compensate better for decreased amounts of water by adapting the management plan for the reservoir volume (Blackshear, 2011).

The nexus between climate change and hydropower generation is a complex one as it is dependent on geography and socioeconomic conditions of the country. In China, Wang et al. (2014) found that the impacts of climate change on hydropower generation of every province are distinctly different with higher in the Southwest part having a higher vulnerability than the Central. Further, Blackshear (2011) predicted that as climate change intensifies that it would be more difficult for hydropower facilities along the Mekong River to predict river discharge and to generate an even supply of power. In some parts of North America, peak flows, lower summer streamflows, and a lengthened
summer low flow period will likely exacerbate competition over water use for hydropower production, in-stream flow protection, and irrigation (Casola et al., 2005). On average, California could lose up to 20 percent of its hydropower generation under dry climate change, which can result in 8 to 18 percent reduction in hydropower revenues for producers (University of California – Riverside 2012).

More frequent droughts would significantly reduce hydropower in some years. For example, in Brazil a prolonged drought, one of the worst since records began in the 1930s reduced hydroelectric capacity for Sao Paulo was at near zero (Appleyard 2015). Recently, a four-year drought, which is partly explained by climate change, has had a dramatic effect on California’s power system and specifically on its portfolio of major hydropower projects. The effective result of the drought has been to roughly half the hydropower capacity available within the state over a period of a few years (Appleyard 2015).

In the European Alps, A Green Advisor Report (2011) reported that for nine climate scenarios analysed the energy production of the Prättigau hydropower plant will increase. In Iberian Peninsula, Climate change is expected to have a negative impact on hydropower with changes in river runoff (Pereira-Cardenal et al., 2014).

On SIDS, the impact of climate change on hydropower varies. In Cameroon by 2050 and 2080 total long-term average hydro-energy generation at some plants vary between -10% and +5% of the base case value (present hydrology (Grijsen, 2014). Further, it was shown that for some stations it was shown that hydropower production was not very sensitive to runoff changes, unless decreases in runoff exceed 20% (Grijsen, 2014). In Samoa, traditionally where 30% to 40% of its annual electricity was generated by hydropower. However, hydropower has come to seem less dependable due to periodic droughts and floods which have been linked to climate change (IRENA 2014).

Overall the literature suggests that decision making for hydropower generation under climate change scenarios have to be based on site specific evaluations.

3. Research site

The Cumberland watershed (Figure 1 is one of sixteen major catchments in SVG and has an area of 20.3 km$^2$ and (CWSA 2012). Almost 50% of the catchment (9.8 km$^2$) forms part of the Islands’ protected forestry reserve occupies area. Two important facilities (The Hermitage water supply system and the Cumberland Hydro-Electric plants) are located in the watershed.

The Cumberland Hydro Electrical Development is the newest of three Hydro Electrical systems on the island and includes three Run-of-River generating stations (at Grove, Spring Village and Cumberland) which are linked by a series of diversion weirs, channels and pipelines. These facilities produce electricity without impounding any significant amount of water upstream. There are little changes of flow downstream of the plants due to the plants.
Current water abstraction from the catchment for potable water supply is about 3000 m$^3$ per day and this is expected to increase to about 3900 m$^3$ per day by 2031 (CWSA 2012).

4. Methodology

Analysis of potential climate change impacts on hydropower requires integrating a hydrological model, with the projected climatic data based on scenarios of future climate variability and a regression model for converting streamflow to the generation of hydropower.

The Cumberland catchment was divided into 5 sub-catchments as shown in Figure 1. The predicted variations in rainfall and temperature...
(minimum, average and maximum) for three climate change scenarios were obtained from the UNDCCCP for SVG (McSweeney, New, and Lizcano 2008). Rainfall data from three sites within the Cumberland catchment (Hermitage, Convent and Spring) and one from the Belle Isle climate station in an adjacent catchment (see Appendix A) were used in the simulations. Precipitation for each sub-catchment was assigned using the inverse distance method provided by for in the HEC-HMS software. Further, the projected precipitation changes used in the study are shown in Figure 2. Average daily stream flow values from Hermitage Station were used for the calibration and simulations.

Land use and soil type data in a GIS format from the Forestry Department (Ministry of Agriculture 2008) supported the use of the SCS Curve Number (CN). For each sub-catchment, SCS CN values were benchmarked to the values found by John (2009) in similar catchments in St. Vincent. No allowance was made for possible changes in soil conditions and land cover in the future.

Temperature data from the Belle Isle Climate Station was used to calculate the potential evapotranspiration (PET) using the Thornthwaite method (Thompson et al., 2014). Monthly PET values were computed offline using an EXCEL spreadsheet and inputted to the rainfall runoff model. The future values of PET were obtained by adjusting the average monthly temperatures (based on 2009 to 2015 values) progressively over the projected period by the amounts proportional to the simulated temperature increases for the 3 timelines and 3 scenarios.

A statistical model using the monthly streamflow and electricity generation data for 2008 to 2012 was developed by using regression analysis to develop relationship between flows and electricity generated. This relationship was used to estimate electricity generation from predicted streamflow under the 3 climate change scenarios.

### 5. The Hydrologic Model

The Hydrologic Modelling System (HEC-HMS) which was used in the study is designed to simulate the complete hydrologic processes of dendritic watershed systems with for continuous simulation including evapo-transpiration, and soil moisture accounting (US Army Coop Engineers, 2015). It takes into account the influences of physical parameters of the watershed such as climatic, topography, land-use and soil data representing conditions over the watershed to simulate runoff. Two steps have been conducted to simulate the hydrologic modelling using HEC-HMS in the Cumberland watershed. Initially, the watershed was divided into six homogeneous sub-watersheds using Hec-Geo-HMS to get the sub-watershed geometric data (Figure 1). Then, the hydrological modelling was developed in HEC-HMS for the watershed using all the parameters obtained from the previous step. The model provides the Curve Number (CN) value for the different land-use considering the four soil groups. To construct the CN value of Cumberland watershed, land-use and soil maps available in GIS format
(see Appendix A) were analysed. The standard shape was employed in HEC-HMS to define the shape of the unit hydrograph. In this method, the standard lag is defined as the length of time between the centroid of precipitation mass and the peak flow of the resulting hydrograph.

6. Results and discussions

2. Calibration of the model

The model was calibrated using monthly climate data (temperature and precipitation) for the period 2009 to 2012. It was then tested on data for 2013. As the volumes of flow were more critical to the generation of power, fitting the simulated flow volumes to observed flow volumes was given higher priority to matching peak flows which would have been more important if flooding was being studied. Generally, there was poor match for peak flows as shown in Figure 3. Preliminary simulations resulted in an overall difference of about 20% between simulated and observed. Calibration was better during the dry season, when overall precipitation and the streamflow peaks were lower. The model was not sensitive to the extremes in precipitation. In any case the time intervals used in the simulation may have been too large to capture high intensity precipitation which is characteristic of the site.

Flows due to climate change

The simulated flows indicate that average streamflows in the Cumberland catchment could be reduced by 5% to 22% by the year 2090 as shown in Figure 4. The largest reduction would be experienced under the A1 scenario.
The spread in the flows in the future can range from 28% to 60% of the baseline flows from 2030 to 2090 respectively for an A1 climate change scenario, as shown in Figure 2*. Similar ranges were found for the A1B and B1 scenarios.

**Electricity generation**

The relationship between streamflows and generation based on the baseline data (2009 to 2012) was of the form in Equation 1 with an $R^2$ value of 0.702.

$$E = Q^{0.926}$$

Where $E =$ electricity generated (MKh) and $Q =$ total flow (Mm$^3$)
As expected any decrease in streamflow would result in reduced electricity production. Figure 6 shows the estimated electricity generation relative to the production from the baseline flows. Production follows the trend and magnitudes of streamflows under the climate change scenarios.

7. Conclusions

The conclusions of this study are primarily based on projected changes in annual precipitation, temperature, potential evapotranspiration and runoff. Using the limited available data, it is seen that streamflow in the Cumberland watershed would be significantly reduced in the new 75 years and would adversely impact on the ability of the current hydropower generating plant to maintain the current level of production.

The study is a first step to better understanding the nexus between climate change and water resources in SVG and more work needs to be done as better data sets become available.

8. References


Appendix

Projected changes in temperature and precipitation for the Cumberland site.

<table>
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<th>SRES scenario</th>
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<th>2060’s</th>
<th>2090’s</th>
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<td></td>
<td>Min</td>
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<td>Max</td>
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<tr>
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<td>T(°C) P(%)</td>
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<td>1</td>
</tr>
<tr>
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Appendix A

Map of Cumberland Watershed Showing Data Sources

Legend
- Cumberland buildings
- Rain gauges
- SV_Water_Leve
- Cumberland roads
- Cumberland river