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CLIMATE CHANGE EFFECTS ON GROUNDWATER RESOURCES

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Abstract: Climate change is normally defined as any change in climate over time, whether due to natural variability or from human activities. It poses uncertainties to the supply and management of water resources. Although climate change has been widely recognized, research on the effects of climate change on groundwater system is relatively limited. Groundwater resources are related to climate change through the direct interaction with surface water resources, such as lakes and rivers, and indirectly through the recharge process. This article presents the likely effects of climate change on groundwater resources and methodology to assess the impact of climate change on groundwater resources.
Keywords: Climate change; Groundwater recharge; MODFLOW; Numerical modeling; Seawater intrusion; UnSat Suite.
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INTRODUCTION

Water is indispensable for life, but its availability at a sustainable quality and quantity is threatened by many factors, of which climate plays a leading role. The Intergovernmental Panel on Climate Change (IPCC) defines climate as "*the average weather in terms of the mean and its variability over a certain time-span and a certain area*" and a statistically significant variation of the mean state of the climate or of its variability lasting for decades or longer, is referred to as climate change. Climate change, also called global warming, refers to the rise in average surface temperatures on Earth. An overwhelming scientific consensus maintains that climate change is due primarily to the human use of fossil fuels, which releases carbon dioxide and other greenhouse gases into the air. The gases trap heat within the atmosphere, which can have a range of effects on ecosystems, including rising sea levels, severe weather events, and droughts etc. Evidence is mounting that we are in a period of climate change brought about by increasing atmospheric concentrations of greenhouse gases. Atmospheric carbon dioxide levels have continually increased since the 1950s. The continuation of this phenomenon may significantly alter global and local climate characteristics, including temperature and precipitation.

HYDROLOGICAL IMPACTS OF CLIMATE CHANGE

The Intergovernmental Panel on Climate Change (IPCC, 2007) estimates that the global mean surface temperature has increased 0.6± 0.2°C since 1861, and predicts an increase of 2 to 4°C over the next 100 years. Global sea levels have risen between 10 and 25 cm since the late 19th century. Climate change poses uncertainties to the supply and management of water resources.

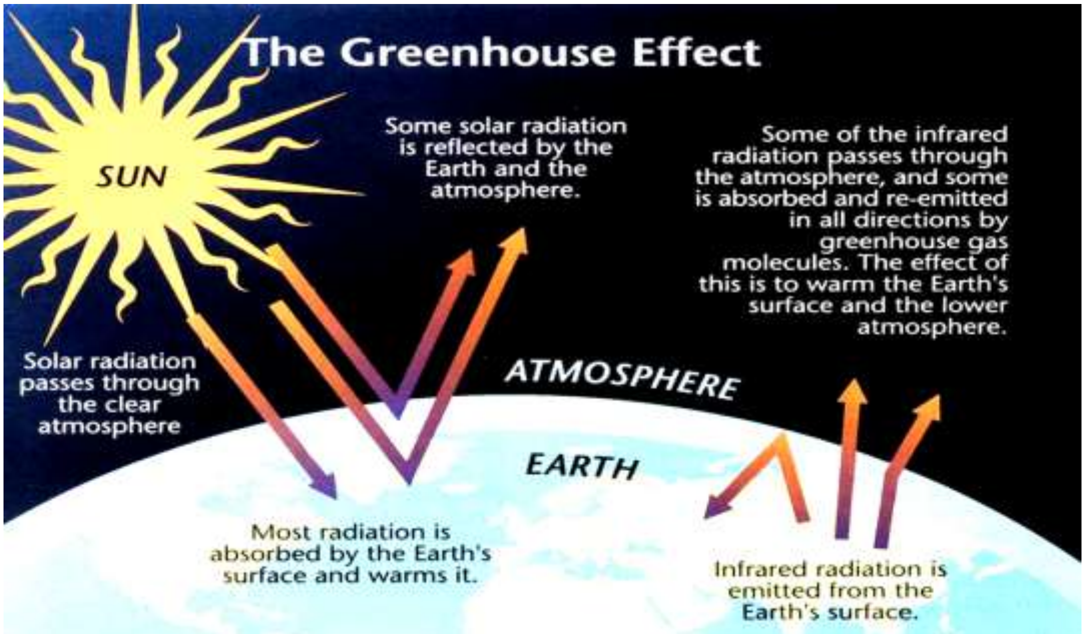

Figure 1. The Greenhouse Effect

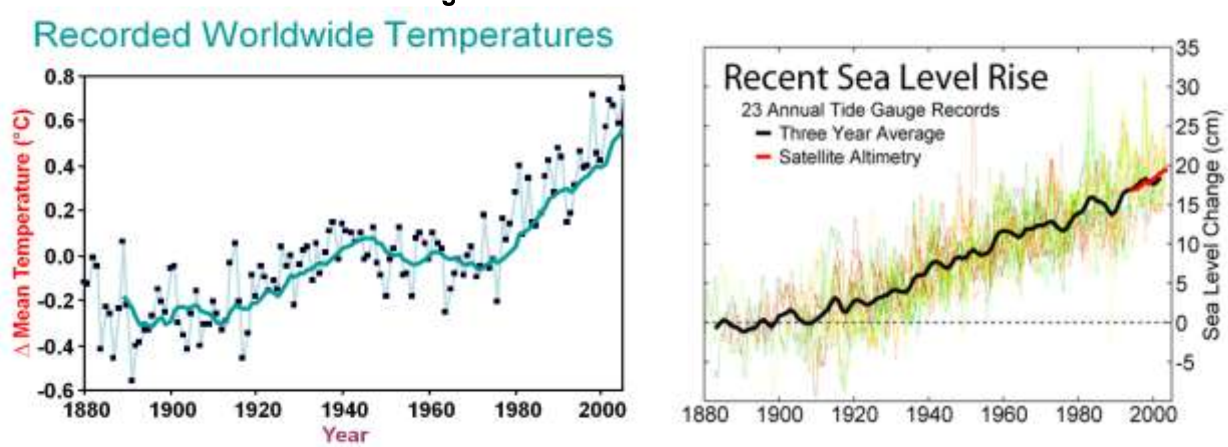

Figure 2. Recorded Worldwide Temperatures & Recent Sea Level Rise

As a direct consequence of warmer temperatures, the hydrologic cycle will undergo significant impact with accompanying changes in the rates of precipitation and evaporation. Predictions include higher incidences of severe weather events, a higher likelihood of flooding, and more droughts. The impact would be particularly severe in the tropical areas, which mainly consist of developing countries, including India. Temperature increases affect the hydrologic cycle by directly increasing evaporation of available surface water and vegetation transpiration. Consequently, these changes can influence precipitation amounts, timings and intensity rates, and indirectly impact the flux and storage of water in surface and subsurface reservoirs *i.e.* lakes, soil moisture, and groundwater. In addition, there may be other associated impacts, such as sea water intrusion, water quality deterioration, potable water shortage, etc.

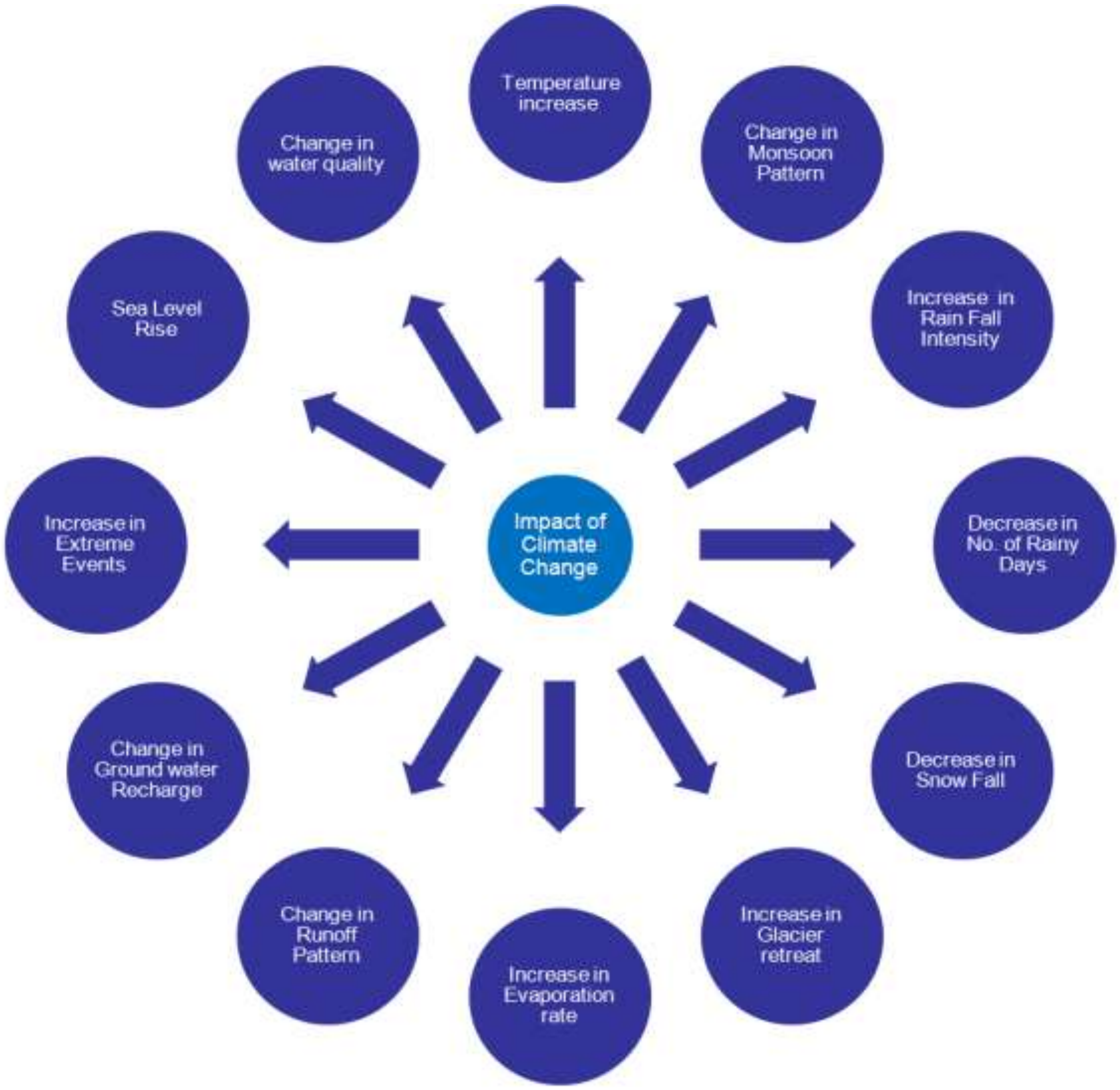

Figure 3. Hydrological Impacts of Climate Change

Climate change can have profound effects on the hydrologic cycle through precipitation, evapotranspiration, and soil moisture with increasing temperatures. The hydrologic cycle will be intensified with more evaporation and more precipitation. However, the extra precipitation will be unequally distributed around the globe. Some parts of the world may see significant reductions in precipitation or major alterations in the timing of wet and dry seasons. Many rivers and streams that are fed by glacier runoff could be significantly impacted as a result of climate change. As glacier retreat accelerates, increased summer runoff could occur. However, when the glaciers have largely melted, the late summer and fall glacial input into streams and rivers may be lost, resulting in a significant reduction in flow in some cases (Singh and Kumar, 2010). Water resource management plans increasingly need to incorporate the affects of global climate change in order to accurately predict future supplies. Information on the local or regional impacts of climate change on hydrological processes and water resources is becoming more important. The effects of global warming and climatic change require multi-disciplinary research, especially when considering hydrology and global water resources.

EFFECTS OF CLIMATE CHANGE ON GROUNDWATER RESOURCES

Although the most noticeable impacts of climate change could be fluctuations in surface water levels and quality, the greatest concern of water managers and government is the potential decrease and quality of groundwater supplies, as it is the main available potable water supply source for human consumption and irrigation of agriculture produce worldwide. Because groundwater aquifers are recharged mainly by precipitation or through interaction with surface water bodies, the direct influence of climate change on precipitation and surface water ultimately affects groundwater systems. It is increasingly recognized that groundwater cannot be considered in isolation from the landscape above, the society with which it 'interacts', or from the regional hydrological cycle, but needs to be managed holistically. In understanding the likely consequences of possible future (climate and non-climate) changes on groundwater systems and the regional hydrological cycle, an important (but not exclusive) component to understand is the influence that these factors exert on recharge and runoff. It is important to consider the potential impacts of climate change on groundwater systems. As part of the hydrologic cycle, it can be anticipated that groundwater systems will be affected by changes in recharge (which encompasses changes in precipitation and evapotranspiration), potentially by changes in the nature of the interactions between the groundwater and surface water systems, and changes in use related to irrigation.

(a) Soil Moisture

The amount of water stored in the soil is fundamentally important to agriculture and has an influence on the rate of actual evaporation, groundwater recharge, and generation of runoff (IPCC, 2001). Soil moisture contents are directly simulated by global climate models, albeit over a very coarse spatial resolution, and outputs from these models give an indication of possible directions of change. The local effects of climate change on soil moisture, however, will vary not only with the degree of climate change but also with soil characteristics. The water-holding capacity of soil will affect possible changes in soil moisture deficits; the lower the capacity, the greater the sensitivity to climate change. Climate change also may affect soil characteristics, perhaps through changes in waterlogging or cracking, which in turn may affect soil moisture storage properties. Infiltration capacity and water-holding capacity of many soils are influenced by the frequency and intensity of freezing.

(b) Groundwater Recharge

Groundwater is the major source of water across much of the world, particularly in rural areas in arid and semi-arid regions, but there has been very little research on the potential effects of climate change. Aquifers generally are replenished by effective rainfall, rivers, and lakes. This water may reach the aquifer rapidly, through macro-pores or fissures, or more slowly by infiltrating through soils and permeable rocks overlying the aquifer. A change in the amount of effective rainfall will alter recharge, but so will a change in the duration of the recharge season. Increased winter rainfall, as projected under most scenarios for mid-latitudes, generally is likely to result in increased groundwater recharge. However, higher evaporation may mean that soil deficits persist for longer and commence earlier, offsetting an increase in total effective rainfall. Various types of aquifer will be recharged differently. The main types are unconfined and confined aquifers. An unconfined aquifer is recharged directly by local rainfall, rivers, and lakes, and the rate of recharge will be influenced by the permeability of overlying rocks and soils.

Shallow unconfined aquifers along floodplains, which are most common in semi-arid and arid environments, are recharged by seasonal streamflows and can be depleted directly by evaporation. Changes in recharge therefore will be determined by changes in the duration of flow of these streams, which may locally increase or decrease, and the permeability of the overlying beds, but increased evaporative demands would tend to lead to lower groundwater storage. The thick layer of sands substantially reduces the impact of evaporation. Unconfined aquifers are sensitive to local climate change, abstraction, and seawater intrusion. However, quantification of recharge is complicated by the characteristics of the aquifers themselves as well as overlying rocks and soils. A confined aquifer, on the other hand, is characterized by an overlying bed that is impermeable, and local rainfall does not influence the aquifer. It is normally recharged from lakes, rivers, and rainfall that may occur at distances ranging from a few kilometers to thousands of kilometers. Aside from the influence of climate, recharge to aquifers is very much dependent on the characteristics of the aquifer media and the properties of the overlying soils. Several approaches can be used to estimate recharge based on surface water, unsaturated zone and groundwater data. Among these approaches, numerical modeling is the only tool that can predict recharge. Modeling is also extremely useful for identifying the relative importance of different controls on recharge, provided that the model realistically accounts for all the processes involved. However, the accuracy of recharge estimates depends largely on the availability of high quality hydrogeologic and climatic data. Determining the potential impact of climate change on groundwater resources, in particular, is difficult due to the complexity of the recharge process, and the variation of recharge within and between different climatic zones.

Attempts have been made to calculate the rate of recharge by using carbon-14 isotopes and other modeling techniques. This has been possible for aquifers that are recharged from short distances and after short durations. However, recharge that takes place from long distances and after decades or centuries has been problematic to calculate with accuracy, making estimation of the impacts of climate change difficult. The medium through which recharge takes place often is poorly known and very heterogeneous, again challenging recharge modeling. In general, there is a need to intensify research on modeling techniques, aquifer characteristics, recharge rates, and seawater intrusion, as well as monitoring of groundwater abstractions. This research will provide a sound basis for assessment of the impacts of climate change and sea-level rise on recharge and groundwater resources.

(c) Coastal Aquifers

When considering water resources in coastal zones, coastal aquifers are important sources of freshwater. However, salinity intrusion can be a major problem in these zones. Salinity intrusion refers to replacement of freshwater in coastal aquifers by saltwater. It leads to a reduction of available fresh groundwater resources. Changes in climatic variables can significantly alter groundwater recharge rates for major aquifer systems and thus affect the availability of fresh groundwater. Salinization of coastal aquifers is a function of the reduction of groundwater recharge and results in a reduction of fresh groundwater resources. Sea-level rise will cause saline intrusion into coastal aquifers, with the amount of intrusion depending on local groundwater gradients. Shallow coastal aquifers are at greatest risk. Groundwater in low-lying islands therefore is very sensitive to change. A reduction in precipitation coupled with sea-level rise would not only cause a diminution of the harvestable volume of water; it also would reduce the size of the narrow freshwater lense. For many small island states, seawater intrusion into freshwater aquifers has been observed as a result of over-pumping of aquifers. Any sea-level rise would worsen the situation. To assess the impacts of potential climate change on fresh groundwater resources, we should focus on changes in groundwater recharge and sea level rise on the loss of fresh groundwater resources in water resources stressed coastal aquifers.

RESEARCH STUDIES

There have been many studies relating the effect of climate changes on surface water bodies. However, very little research exists on the potential effects of climate change on groundwater, although groundwater is the major source of drinking water across much of the world and plays a vital role in maintaining the ecological value of an area. Available studies (Kumar and Singh, 2012) show that groundwater recharge and discharge conditions are reflection of the precipitation regime, climatic variables, landscape characteristics and human impacts such as agricultural drainage and flow regulation. Hence, predicting the behavior of recharge and discharge conditions under future climatic and other changes is of great importance for integrated water management. The principal focus of climate change research with regard to groundwater has been on quantifying the likely direct impacts of changing precipitation and temperature patterns. Such studies have used a range of modelling techniques such as soil water balance models, empirical models, conceptual models and more complex distributed models, but all have derived changes in groundwater recharge assuming parameters other than precipitation and temperature remaining constant. Studies which consider the indirect effects derived from climate-change-induced alterations in soil, land cover, salt-water intrusion due to rising sea levels and changes in water demand are less common. These studies represent a move away from impact studies (which may be considered to be vertically integrated, in which climate change acts upon an environmental compartment) towards horizontally integrated studies in which environmental compartments interact with each other. However, they remain an incomplete assessment of the pressures facing groundwater resources associated with the direct and indirect effects of future climate and socio-economic change. Previous studies have typically coupled climate change scenarios with hydrological models, and have generally investigated the impact of climate change on water resources in different areas. The scientific understanding of an aquifer's response to climate change has been studied in several locations within the past decade. These studies link atmospheric models to unsaturated soil models, which, in some cases, were further linked into a groundwater model. The groundwater models used were calibrated to current groundwater conditions and stressed under different predicted climate change scenarios.

METHODOLOGY TO ASSESS THE IMPACT OF CLIMATE CHANGE ON GROUNDWATER

There are two main parameters that could have a significant impact on groundwater levels: recharge and river stage/discharge. To assess the impact on the groundwater system to changes in these two parameters, it is necessary to have a calibrated flow model and to conduct a sensitivity analysis by varying these two parameters and calculating changes to the water balance *e.g.* differences in water levels. The research objectives can be:

a) To develop a conceptual model of the hydrogeology of the study region;
b) To investigate how regional and local weather events affect recharge;
c) To determine potential impacts of climate change on recharge for the study area, and to assess the sensitivity of the results to different global climate models;
d) To develop and calibrate a three-dimensional groundwater flow model of the region and to use that model to assess the impacts of climate change on groundwater resources.

The methodology consists of three main steps (Toews, 2007). To begin with, climate scenarios can be formulated for the future years such as 2050 and 2100. This is done by assigning percentage or value changes of climatic variables on a seasonal and/or annual basis only for the future years relative to the present year. Secondly, based on these scenarios and present situation, seasonal and annual recharge, evapotranspiration and runoff are simulated with the WHI UnSat Suite (HELP module for recharge) and/or WetSpass model. Finally, the annual recharge outputs from WHI UnSat Suite or WetSpass model are used to simulate groundwater system conditions using steadystate MODFLOW model setups for the present condition and for the future years. A typical flow chart for various aspects of such a study is shown in Figure 4 which shows the connection from the climate analysis, to recharge simulation, and finally to a groundwater model. Recharge is applied to a three-dimensional groundwater flow model, which is calibrated to historical water levels. Transient simulations are undertaken to investigate the temporal response of the aquifer system to historic and future climate periods. Tasks in the upper part of the chart assemble several climate data sets for current and future predicted conditions, which are used to simulate recharge using HELP module of WHI UnSat Suite. The soil layers are parameterized using a pedotransfer function program, which utilizes detailed soil survey measurements. Mapped monthly recharge from HELP is then used in a three-dimensional MODFLOW model to simulate transient saturated groundwater flow. As per Holman, 2006; if the likely consequences of future changes of groundwater recharge, resulting from both climate and socio-economic change, are to be assessed, hydrogeologists must increasingly work with researchers from other disciplines, such as socio-economists, agricultural modelers and soil scientists.

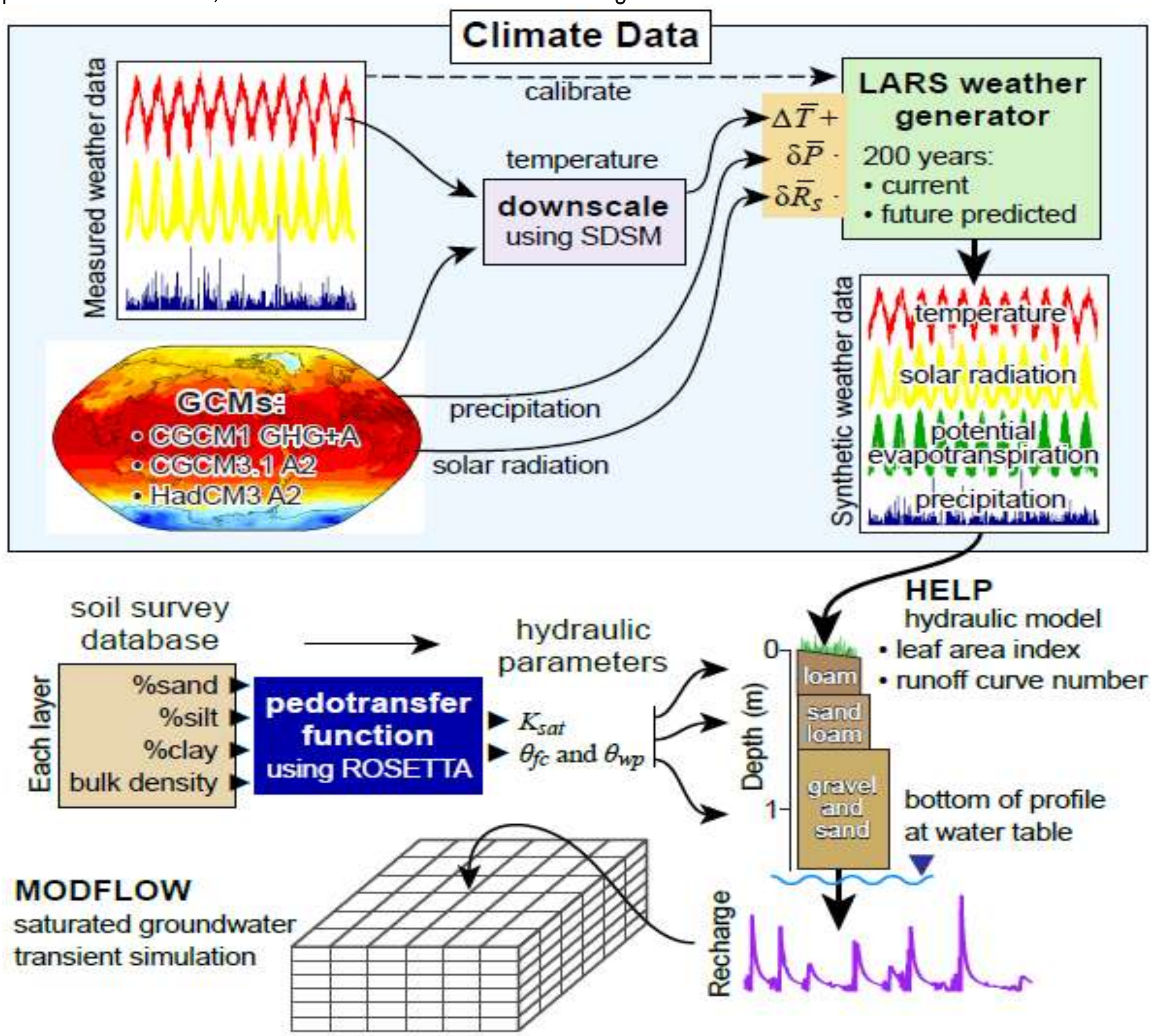

Figure 4. Flow Chart of Tasks (Toews, 2007)

CONCLUSION

While climate change affects surface water resources directly through changes in the major long-term climate variables such as air temperature, precipitation, and evapo-transpiration, the relationship between the changing climate variables and groundwater is more complicated and poorly understood. The greater variability in rainfall could mean more frequent and prolonged periods of high or low groundwater levels, and saline intrusion in coastal aquifers due to sea level rise and resource reduction. Groundwater resources are related to climate change through the direct interaction with surface water resources, such as lakes and rivers, and indirectly through the recharge process. The direct effect of climate change on groundwater resources depends upon the change in the volume and distribution of groundwater recharge. Therefore, quantifying the impact of climate change on groundwater resources requires not only reliable forecasting of changes in the major climatic variables, but also accurate estimation of groundwater recharge

REFERENCES

Holman, I. P. (2006). Climate change impacts on groundwater recharge-uncertainty, shortcomings, and the way forward? *Hydrogeology Journal*, 14:637–647.

IPCC (2001). Climate Change 2001: Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change *In*: James J. McCarthy, Osvaldo F. Canziani, Neil A. Leary, David J. Dokken, Kasey S. White (Eds.), Cambridge University Press, Cambridge, UK.

IPCC (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, *In*: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M., Miller, H. L. (eds.), Cambridge University Press, Cambridge, UK and New York, NY, USA, 966 p.

Kumar, C. P. and Surjeet Singh (2012). Impact of Climate Change on Groundwater Resources – Status of Research Studies, Proceedings of 3rd International Conference on Climate Change and Sustainable Management of Natural Resources, 5-7 February 2012, Gwalior.

Singh, R. D. and C. P. Kumar (2010). Impact of Climate Change on Groundwater Resources, Proceedings of 2nd National Ground Water Congress, 22nd March 2010, New Delhi, pp. 332-350.

Toews, Michael W. (2007). Modelling Climate Change Impacts on Groundwater Recharge an a Semi-Arid Region, Southern Okanagan, British Columbia, A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the Department of Earth Sciences, Simon Fraser University.

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