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Assessment of Climate Change Impacts on Groundwater Recharge for Different Soil Types-Guelph Region in Grand River Basin, Canada

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Background: Global warming and climate change are widely indicated as important phenomena in the 21st century that cause serious impacts on the global water resources. Changes in temperature, precipitation and evaporation are occurring in regions throughout the world, resulting in changes including, runoff, streamflow and groundwater regimes, reduced water quantity and quality.

Materials and Methods: Relying upon thirty years of base data (1965–1994), three global circulation models (GCM), namely GISS, GFDM and CCC, are utilized to assess impact of climate change to groundwater recharge rates between years 2010 to 2050 for the Guelph region of the Grand River Basin in Canada. The resulting groundwater recharge rates for alternative soil layers are used to assess water balance conditions, and ultimately, the percolation rate to the groundwater using the Visual-HELP model.

Results: While the climate change impact assessment indicates that evaporation will increase and percolation will decrease during summer, increased percolation is indicated in winter due to additional freeze/thaw dimensions of climate change. The net effect is that the impact of climate change, based upon use of GCM models, is expected to increase groundwater recharge rate by 10% on average (7% for CCC, 10.6% for GISS and 12% for GFDM) in future.

Discussion and Conclusions: According to the results of this research in the Guelph region, the monthly average percolation rate is higher with climate change; (i) the percolation rate is increased during winter due to freeze/thaw effects, while (ii) it is decreased during summer due to higher evaporation rate.

Keywords: Climate change, GCM models, Grand River Basin, Groundwater, Guelph, Visual-HELP

1. Background

Global warming and climate change are widely indicated as important phenomena in the 21st century that cause serious impacts on the global water resources. According to IPCC (1), changes in temperature, precipitation and evaporation are occurring in regions throughout the world that result in various changes, including runoff and streamflow regimes, reduced water quality as a result of intensified runoff conditions, and difficulties in meeting societal demands for water supplies. Nevertheless, the degree of regional impacts of climate change varies from one region to another.

Climate change has been predicted to result in more frequent severe extreme events in terms of droughts, floods, and heat waves in different parts of the globe (2), (3), (4). As a regional example in the Middle East, Goodarzi *et al*. (5) have demonstrated that the impact of climate change in semi-arid regions is significant, while Feizi *et al.* (6) have described the variations of temperature and precipitation in Iran that would have resulted in decreased surface water runoff in the central region.

Canada is a vast country and research indicates that climate change will have serious impacts on its water resources (7). In addition to impacts on surface water, impacts on aquifer recharge and groundwater levels also depend on climate. Since more than nine million Canadians rely on groundwater as their source of water supply and each aquifer has different properties, climate change impacts on groundwater are of great importance. According to Maathuis and Thorleifson (8), "groundwater has been and will continue to be an important water supply for industrial, agricultural and residential use on the Canadian prairies."

Along with using statistical approaches, Global Circulation Models (GCMs) represent a practical approach to assess the impact of climate change in a region. In USA and Canada, three of the more important GCMs include Goddard Institute for Space Sciences (GISS) (9), Geophysical Fluid Dynamics Laboratory/NOAA (GFDL) (10), and the Canadian Centre for Climate Modeling (CCC) (11). Although prediction of future climate conditions by the GCMs is still uncertain, recent studies suggest that higher air temperatures and lower streamflows are expected in southern Ontario (12), (13), (14).

Using alternative climate GCM models, such as GISS87, GFDL87, and CCC92, Smith and McBean (15) predicted reductions in annual surface runoff changes by 2050 of the order of –11%, 12% and 22% in the Grand River Basin, respectively. Jyrkama and Sykes (16) estimated the impact of climate change in terms of spatial variability of the groundwater recharge in the Grand River watershed, taking forty years (1960-2000) basic data as a reference; they concluded an estimated increase of potential recharge rate by approximately 100 mm/year. MODFLOW model has also been used to estimate climate change impacts on groundwater recharge in Lansing, Michigan, using the outputs from two GCM models (17) and three climate scenarios of downscaled GCM outputs in two small aquifers in western Canada (18).

2. Objective

Since changes in temperature and precipitation will alter recharge to groundwater aquifers, there will be shifts in water table levels in unconfined aquifers as a first response (19). Therefore, an important first step in assessment of the vulnerabilities to climate change is to understand these impacts in a specific context. Specifically, the research herein is focused on the estimation of impacts of global climate change on the hydrologic budget in general, and groundwater percolation or recharge in particular, for the Grand River Basin. Therefore, the objective of this study is to assess the rate of groundwater recharge in different types of soils with the outputs of GCMs models and use of the Visual-HELP simulation model. The results are used to indicate the overall rate percentage of the recharge based on the GCMs outputs between 2010- 2050.

3. Materials and Methods

3.1. The Grand River Basin

The climate conditions vary across the Grand River Basin, demonstrating four different climate zones. The Basin is over 300 km from north to south, drains 6740 km^2 of southern Ontario (20). Annual average precipitation varies from 850 mm to over 1000 mm, with the higher recorded precipitation in the northwest and lower levels in the southeast. The highest monthly precipitation occurs in July and August, while the driest months are January and February. Also, the mean annual temperature ranges from 5°C in the higher elevations in the north to 8°C at the lakeshore (21). The Grand River Basin is lying on highly productive aquifers, the Guelph and Salina formations in the Guelph area and, hence, groundwater recharge to these aquifers is extremely important, particularly for a growing population in the Basin (currently 790,000 people) that depends almost entirely on the groundwater (Figure 1).

3.2. GCM models outputs and downscaling

In general, for predicting and reflecting the future impacts of climate change on regional water resources, alternative GCM models outputs need to be compared to historical climate conditions.

However, GCM models run at a large special resolution (in the range of 100-300 km), requiring the outputs of these models to be downscaled for local studies. Downscaling is a process that transforms coarse-resolution GCM outputs into smaller resolution to facilitate regional climatic influences.

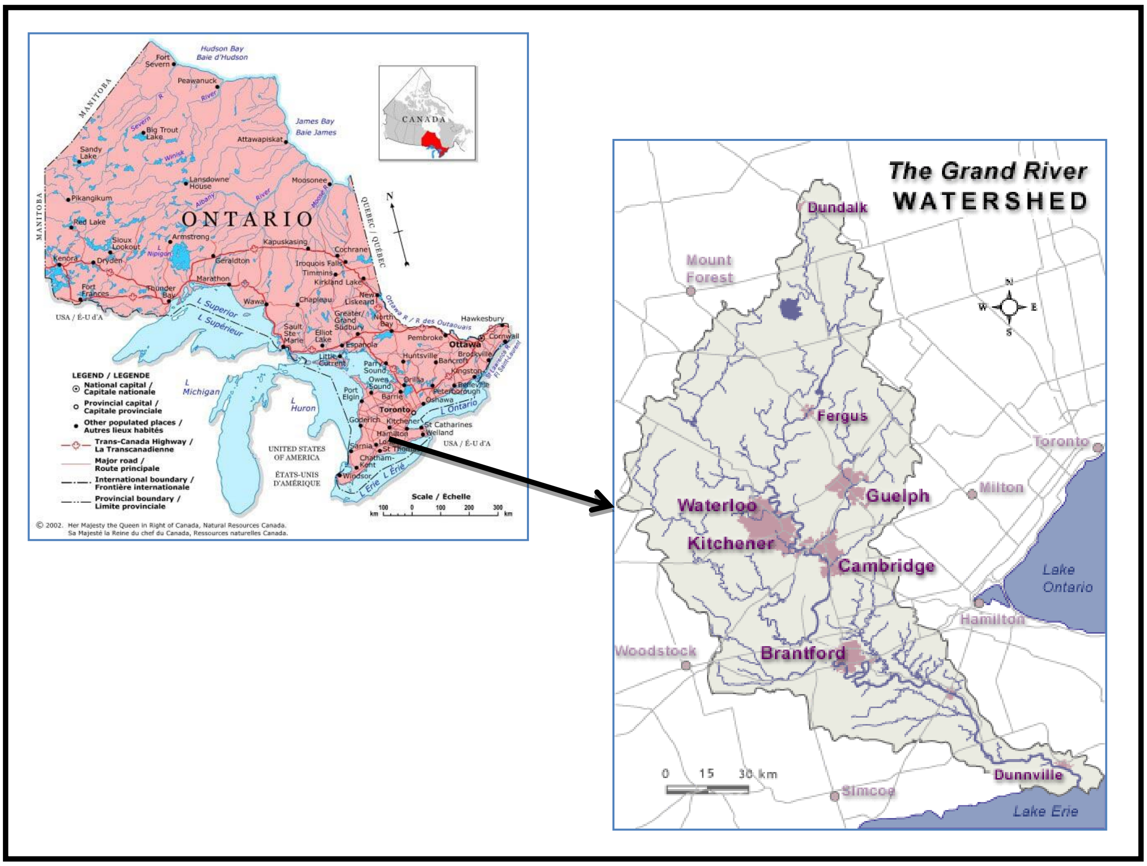

Figure 1 Location of Guelph in the Grand River Basin in Ontario (Ref: Google Map)

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Downscaling is categorized into three methods: change factor (CF) method, statistical such as regression methods, and dynamic methods (22), (23). In this research, the change factor method is used for downscaling of the GCMs outputs.

To construct climate change scenarios of each GCMs, the differences and ratios for the temperature and precipitation were calculated based on the long term monthly average of future and base case periods (1965-1994) using Equations (1) and (2), respectively (24), (25).

$$\Delta T = (\bar{T}_{F.} - \bar{T}_{B.}) \quad (1)$$

$$\Delta P = (\bar{P}_{F.} / \bar{P}_{B.}) \quad (2)$$

ΔT and ΔP: climate change scenarios of the temperature and precipitation, respectively,

$\bar{T}_{F.}$ and $\bar{P}_{F.}$: the average temperature and precipitation simulated by the GCMs in the future periods,

$\bar{T}_{B.}$ and $\bar{P}_{B.}$: the average temperature and precipitation simulated by the GCMs for the base case.

For calculating time series of future climate scenarios, ΔT and ΔP are added to the base case values for temperature (Eq. 3), and multiplied for precipitation (Eq.4).

$$T_F = T_{B.} + \Delta T \quad (3)$$

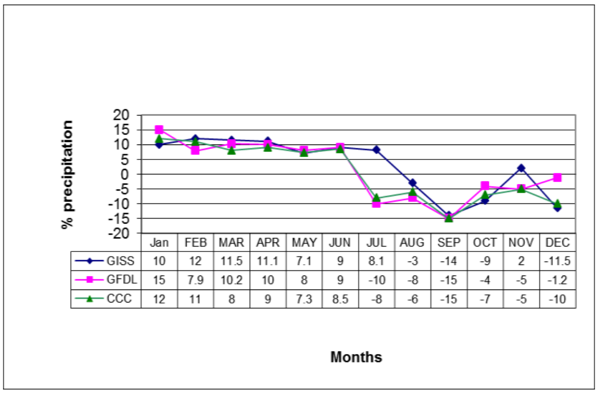
$$P_F = P_{B.} * \Delta P \quad (4)$$

Table 1 and Figure 2 summarize the comparison between GCMs outputs for monthly temperature and precipitation with the base case (1965-1994).

The magnitudes of precipitation and temperature for the base case and for the GCM models were used to assess the impacts of climate change (Table 2). The monthly percent changes in precipitation in the modeling scenarios were multiplied for daily data of the corresponding month for thirty years of the historical record (1965-1994). The values in parentheses show the percentage changes in precipitation relative to the base case.

Table 1 Changes in monthly temperature (ºC) and precipitation by GCMs for Grand River Basin (15)

Month	GISS		GFDL		CCC	
	Temp.	Precip.(%)	Temp.	Precip.(%)	Temp.	Precip.(%)
Jan.	5.8	10	6.5	15	10	12
Feb.	5.5	12	6.4	7.9	10.5	11
Mar.	5.1	11.5	6.3	10.2	9	8
Apr.	4.4	11.1	3.95	10	7	9
May	3.7	7.1	3.7	8	5.1	7.3
June	3.2	9	3.3	9	4.6	8.5
July	3.4	8.1	5.5	-10	4.6	-8
Aug.	4.1	-3	5.6	-8	4.8	-6
Sep.	4.9	-14	5.35	-15	4.3	-15
Oct.	5.1	-9	5.4	-4	3.6	-7
Nov.	5.4	2	6	-5	2.1	-5
Dec.	5.8	-11.5	5.5	1.2	2.5	-10
Mean	**4.7**	**2.78**	**5.3**	1.4	**5.7**	**0.4**



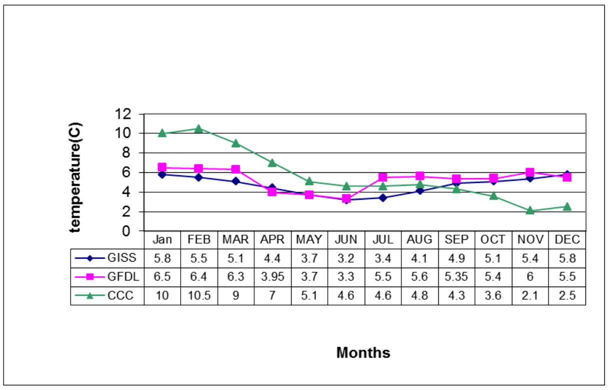


Figure 2 Changes in monthly temperature (°C) and precipitation (%) with three GCMs for Guelph Region

Table 2 Magnitudes of precipitation and temperature for historical data and for three GCM predictions for a scenario of doubling CO_2 concentrations

Models	Annual Precipitation (mm)	Average Temp (°C)
Base Case	871	6.2
GISS	898 (2.7%)	10.8
GFDL	885 (1.4%)	11.5
CCC	875 (0.4%)	11.8

The monthly changes in temperature from the GCMs were added to the daily data of the corresponding month of the thirty years of historical data. The three sets of model results for precipitation and temperatures are pertinent to the Guelph region within the Grand River Basin.

3.3. *Predicted temperature changes with climate change*

The climate change GCM models used in this research showed an increase in annual temperature with a range from 4.6°C to 5.3°C on average. As a result, the different scenarios raised the historical annual temperature from 6.2°C in Guelph to different magnitudes of 10.8°C, 11.5°C and 11.8 °C by GISS, GFDL and CCC (Table 2), respectively. The regional outputs of these models are consistent with global trends, with a greater increase in temperature in the winter months, than in the summer. As a result, winters are expected to become milder, and shorter, with less snowfall, and more frequent snowmelt which has important implications to recharge as described below.

3.4. *Predicted precipitation changes with climate change models*

In comparison with the base case, the increase in historical precipitation from the total amount of annual precipitation was predicted, 2.8% by the GISS model, 1.4% by the GFDL model, while the CCC model entails a small increase (0.4%) (Table 2). Equally important, however, is the variability within the year. The models don't show a significant change in annual precipitation; however, the seasonal pattern indicates a large decrease in precipitation during the summer and early fall, so that while the totals are not expected to change by large amounts, individual seasonal responses change significantly (Table 3).

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3.5. Visual HELP model

According to the basic hydrologic relation, the local water budget of a region is defined by the following equation:

Precipitation = basin channel runoff + evapotranspiration ± changes in storage

To assess the changes in storage and its subsequent recharge, the Visual HELP (Hydrologic Evaluation of Landfill Performance) model was employed, which is an advanced hydrological modeling environment for evaluating potential groundwater movement through the vadose zone to the groundwater table (26). It is a quasi-two-dimensional, deterministic, and water-routing model, which estimates the daily water balance by simulating both the surface and subsurface hydrologic phenomena, including vertical transport velocities (Figure 3). By incorporating the Brooks-Corey relationship for hydraulic conductivity (27), the model is capable of detailed hydraulic assessments of surface storage, snowmelt runoff, infiltration, evapotranspiration, vegetative growth, and soil moisture storage (28).

Table 3 Seasonal magnitudes of precipitation for GCM predictions in comparison with base case (mm)

GCM models	Winter (Dec.-Jan.-Feb.)	Spring (Mar.-Apr.-May)	Summer (June-July-Aug.)	FALL (Sep.-Oct.-Nov.)
GISS	3.5	9.9	4.7	-7
GFDL	5	10	-6.66	-6.66
CCC	1	4	-1.3	-8.66

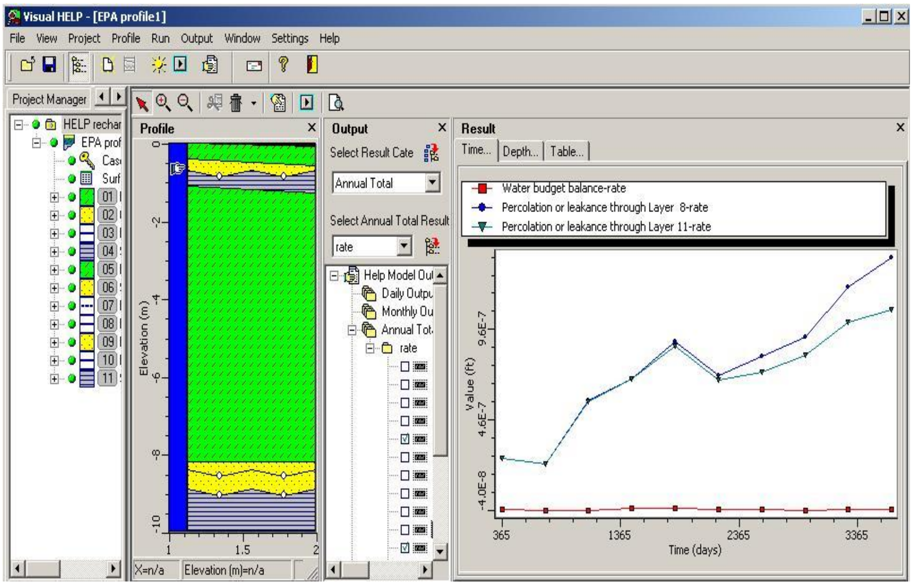

Figure 3 Example of a soil profile result in Visual HELP model

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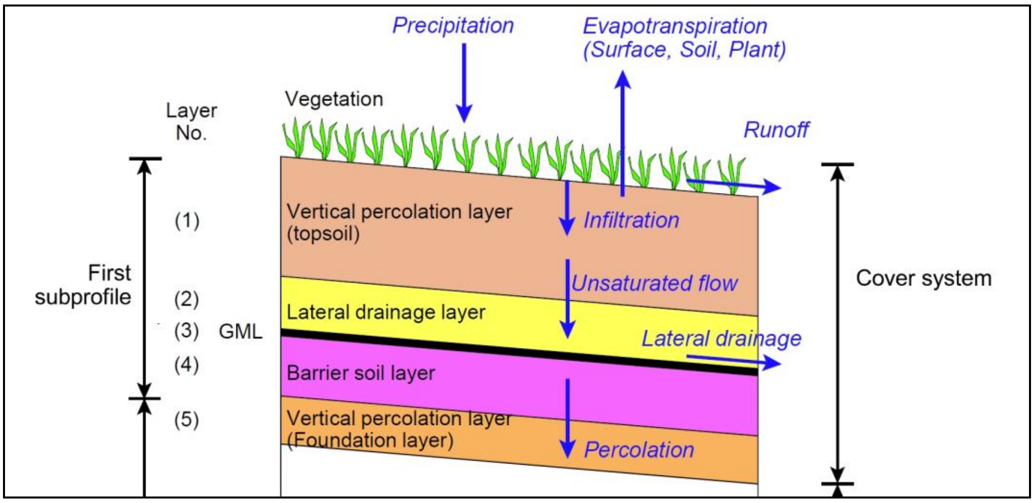


Figure 4 Schematic processes of percolation in Visual HELP model (29)

The processes incorporated into the Visual-HELP modeling include weather-influenced data (evapotranspiration, precipitation, temperature, solar radiation data), and soil data (type of soil and stratigraphy). The surface processes include snowmelt, interception of rainfall by vegetation, surface runoff, and surface evaporation (Figure 4). The subsurface processes include evaporation from the soil profile, plant transpiration, unsaturated vertical drainage, and saturated lateral drainage. The snowmelt and rainfall that does not run off or evaporate, infiltrate into the underlying soil along with any ground melt that does not evaporate.

Validation and verification of any model is defined by comparison of predictions results with matching observational data. According to Jyrkama and Sykes (16) “the direct calibration or comparison of the HELP estimated recharge rates to field measurements are difficult and costly. Therefore, the only reasonable way of adding confidence in the results would be by verifying them indirectly with or within the context of other models”.

4. Results

4.1. Hydrologic data and simulation conditions

The first evaluation was accomplished by using historical records of temperature and precipitation as a base case. For this study, thirty years of daily historical climate data (1965 –1994), as a base case for Guelph region in Ontario, was obtained from Land Resource Science, University of Guelph – Guelph Gauge station (Figure 1). The GCM data were then used to assess the impacts on the groundwater recharge due to alternative climate change scenarios.

Three soil types, the Brookston, Guelph and Fox series, were selected from the soil survey reports No.44 of the Ontario Soil Survey Report (30). The *Brookston* series includes poorly drained soils developed mainly on silt-clay and clay parent materials (henceforth referred to as "clay"). The *Guelph* series comprises soils developed on loam till (henceforth referred to as "till"). Most of the Guelph series occur on level and gently sloping areas and contain inclusions of well-drained soils. The *Fox* series exist on well-drained, mainly medium- and coarse-sized sands. The soil horizon includes loamy sand, and sand, and hence referred to as "sand". These represent the predominant soils throughout the Grand River Basin.

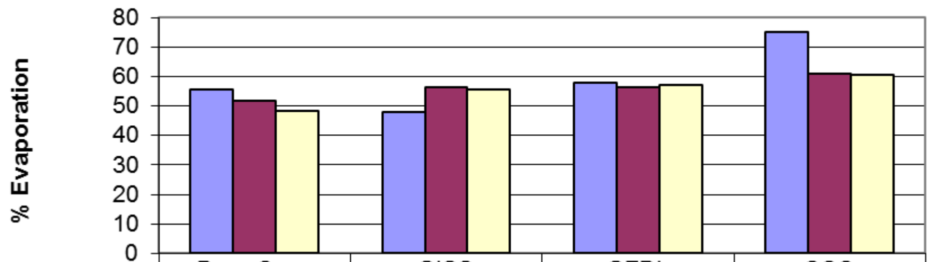
The simulation results of Visual-HELP model for three different soil types, for the base case and GCMs, for evaporation, runoff, and percolation are summarized in Figures 5 to 7. Soil data were unchanged from the base case and the impacts of climate change on percolation for each soil type were calculated. The spatial extent of each soil type was characterized by the physiography of the Guelph region of the Basin, as clay 34%, till 56%, and sand 10% (18).

4.2. Evaporation response to climate change

The demonstrated evaporation quantities are very similar for the base case, regardless of the soil type, namely 55.6%, 51.7% and 48.2% of the total precipitation for clay, till and sandy soils, respectively (Fig 5). The response for evaporation to climate change was found to consistently increase in the order of 16% in GISS, 18% in GFDL, and 30% in CCC, regardless of the soil type. Hence, the impact of climate change is to increase evaporation rate.

4.3. Surface runoff response to climate change

Surface runoff is significantly influenced by the soil type (Figure 6). If evaporation increases, runoff and/or percolation have to decrease. It can be seen that fairly high runoff ratios are obtained because of limited soil storage and the lack of transpiration. This research shows the same trend for different soil types. In the base case, runoff quantities for clay, till and sandy soil were found to be 36.1%, 21.5% and 19.7%, of the total precipitation, respectively. The runoff responses to climate change models were found to decrease for all soil types under the GISS, GFDL and CCC models (Figure 6).



	Base Case	GISS	GFDL	CCC
CLAY	55.6	48	58	75.1
TILL	51.7	56.3	56.2	61
SANDY	48.2	55.7	57	60.5

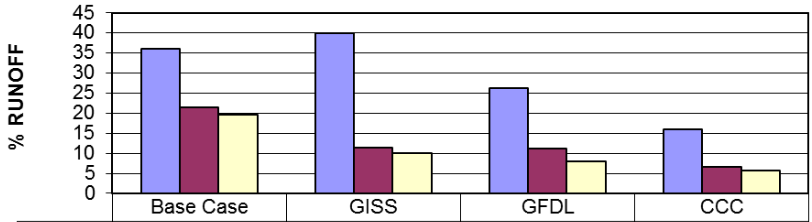
Figure 5 Average annual evaporation (%) in different soils (base case and GCMs)

4.4. Percolation response to climate change

To balance the equation, the sum of runoff, evaporation and percolation percentages has to be approximately 100% of precipitation. Therefore, when surface runoff is high (e.g. for clay soils), percolation is low, and when surface runoff is low (e.g. for sandy soils), percolation is high, due to the relative insensitivity of evaporation to soil type. Till soils demonstrate the highest percolation to groundwater. The percolation for the base case was found to be 8.2% for clay, 26.9% for till, and 32.2% for sandy soil of the total 100% of precipitation (Fig. 7). The GISS, GFDL and CCC models predict greater percolation volumes than the base case, as shown in Table 4.

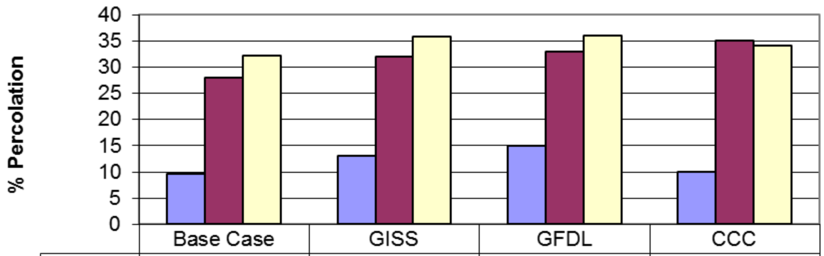
Table 4 demonstrates the average monthly magnitudes of percolation per centimeter for base case and for each of the GCM models calculated by mass balance. In the last row of this Table, the percentage of change for each model is compared with the base case. For example, for the GISS model, the percentage changing has been found by:

(26.1-23.64) / 23.64 *100 = 10.6%



	Base Case	GISS	GFDL	CCC
CLAY	36.1	40	26.2	16
TILL	21.5	11.5	11.2	6.6
SANDY	19.7	10	8	5.6

Figure 6 Average annual runoff (%) in different soils (base case and GCMs)



	Base Case	GISS	GFDL	CCC
CLAY	9.7	13	15	10
TILL	28	32	33	35
SANDY	32.2	35.8	36	34

Figure 7 Percolation average annual percentage in different soils (base case and GCMs)

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Table 4 Average monthly percolation for different models and percentage of changing relative to base case

	Base Case (cm)	**GISS (cm)**	**GFDL (cm)**	**CCC (cm)**
Jan.	3.05	3.5	3.5	3.1
Feb.	1.8	2.5	2.5	2.3
Mar.	1.27	2.3	2.8	3.302
Apr.	1.01	3.05	3.3	3.302
May	2.8	3.8	3.8	3.5
June	2.8	2.3	2.5	2.42
July	1.8	1.5	1.8	1.62
Aug.	1.3	1.3	1.3	1.016
Sep.	1.01	1.01	1.01	0.85
Oct.	1.8	1.5	1.01	1.016
Nov.	1.5	1.3	1.01	0.91
Dec.	3.5	2.03	1.81	1.82
SUM	23.64	26.10	26.45	25.136
Change (%)		10.6%	12.02%	7.2%

5. Discussion

For the three GCM models, the percolation volumes are predicted to increase in till and sandy soils. To examine the circumstances, consider Fig. 8 that shows the average monthly percolation for the base case and for the various climate change models for the weighted percolation assessment. There are two situations: (i) during winter, the percolation rate is increased with GISS and GFDL climate change scenarios. This indicates that the monthly average percolation rate is higher with climate change during winter due to freeze/thaw effects. As a result, water storage on the surface is increased with the climate change scenarios, which increases the infiltration/percolation during winter, and (ii) the percolation rate is decreased during summer with climate change scenarios. During summer under the climate change scenarios, the percolation rate is decreased because the increased temperature with climate change results in higher evaporation rates and hence lower percolation rates.

As the consequence, these results indicate that climate change will increase groundwater recharge for the GISS by 10%, GFDL by 11%, and CCC by 9%.

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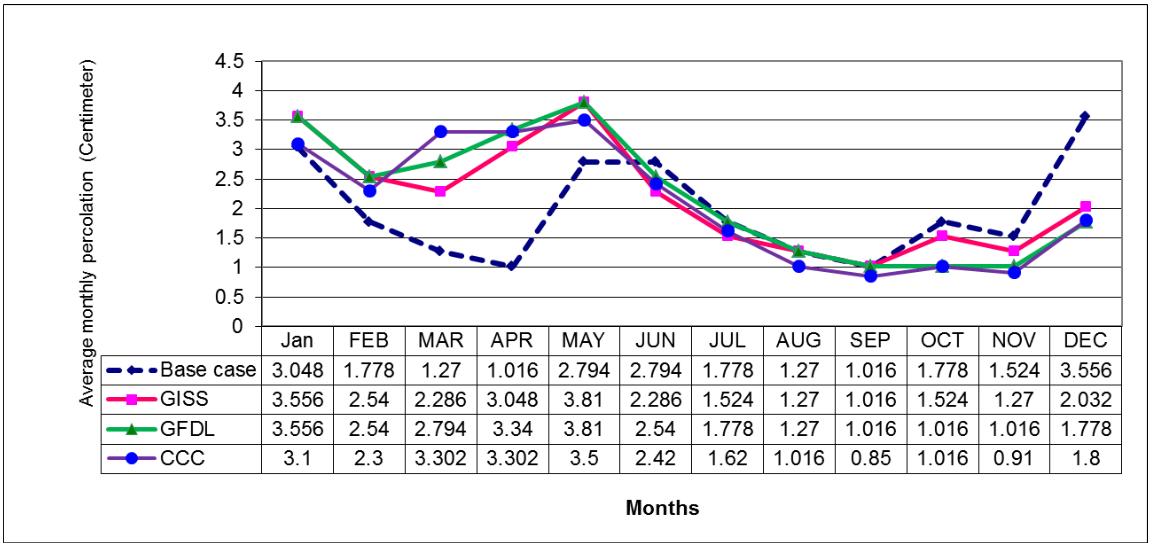

	Jan	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Base case	3.048	1.778	1.27	1.016	2.794	2.794	1.778	1.27	1.016	1.778	1.524	3.556
GISS	3.556	2.54	2.286	3.048	3.81	2.286	1.524	1.27	1.016	1.524	1.27	2.032
GFDL	3.556	2.54	2.794	3.34	3.81	2.54	1.778	1.27	1.016	1.016	1.016	1.778
CCC	3.1	2.3	3.302	3.302	3.5	2.42	1.62	1.016	0.85	1.016	0.91	1.8

Figure 8 Comparison of the average monthly percolation for base case and GCM models

6. Conclusion

Based on the results of this investigation, the climate change will increase the groundwater recharge in the Guelph region of the Grand River Basin in southern Ontario by 7% in CCC, 10.6% in GISS, and 12% the GFDL models. While percolation rates are predicted to decrease in summer due to higher evapotranspiration, it is predicted to increase in winter;, the net overall effect is increased percolation averaging 10% for the three GCM models.

Conflict of Interest

There are no conflicts of interest with respect to the University of Guelph, University of Shahid Beheshti, or the Grand River Authority of Conversation

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Authors' Contributions

Each of the authors contributed to the development of the paper.

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References

1. IPCC, Climate Change 2014: Impacts, adaptation and vulnerability. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change. Cambridge university press, Cambridge, United Kingdom, 2014; p. 688.
2. Zierl B, Bugmann H. Global change impacts on hydrological processes in Alpine catchments. Wat Res Res. 2005; 41(2): 1-13.
3. Penner JE, Lister D, Griggs DJ, Dokken DJM, Farland M. IPCC report about aviation and global atmosphere. ((Eds.), Cambridge university press, UK, 2014; p. 373.

4. UNFCCC, Climate change: impact, vulnerabilities and adaptation in developing countries, United Nations framework convention on climate change (UNFCCC) press, 2010; p. 68.

5. Goodarzi E, Dastorani M, Massah Bavani A, Talebi A. Evaluation of the Change-factor and LARS-WG methods of downscaling for simulation of climatic variables in the future (Case study: Herat Azam Watershed, Yazd - Iran), J Ecop. 2015; 3 (1): 833-846.

6. Feizi V, Mollashahi M, Frajzadeh M, Azizi G. Spatial and Temporal trend analysis of temperature and precipitation in Iran. J Ecop. 2014; 2 (4): 727-742.

7. McBean E, Motiee H, Assessment of impact of climate change on water resources: a long term analysis of the Great Lakes of North America, J. Hydrol. Earth Syst Sci. 2008; (12): 239-255.

8. Maathuis H, Thorleifson LH. Potential impact of climate change on Prairie groundwater supplies: Review of current knowledge. Saskatchewan Research Council, Publication No. 11304-2E00, 2000; p. 93.

9. Hansen J, Ruedy R, Glascoe J, Sato M. 19: GISS analysis of surface temperature change. *J. Geo*, *Res.*, 1999; (104): 30997-31022.

10. Manabe S, Stouffer RJ. Study of abrupt climate change by a coupled ocean-atmosphere model, Quarternary Science Reviews, 2001; (19): 285-299.

11. Boer GJ, Lambert SJ. Multi-model_decadal potential_predictability_of_precipitation_and temperature, Geophys Res Lett. 2008; 35: L05706.

12. Hengeveld HG. Projections for Canada's climate future: a discussion of recent simulations with the Canadian global climate model, Environment Canada, 2000; p. 27.

13. Mortsch L, Allen M, Klaassen J. Development of climate change scenarios for impact and adaptation studies in the Great Lakes – St. Lawrence Basin, International Joint Communication Report Environment Canada; 2005.

14. Kulshreshtha S, Wheaton E. Climate change adaptation and food production in Canada: Some research challenges. WIT Trans Ecol Environ. 2013; 170: 101-112.

15. Smith JV, Mc Bean E. The impact of climate change on surface water resources, Chapter in The Impact of Climate Change on Water in the Grand River Basin, Ontario, University of Waterloo. Waterloo, Ontario 1993; 25-52.

16. Jyrkama MI, Sykes JF. The impact of climate change on spatially varying groundwater recharge in the Grand river watershed (Ontario), J Hydrol. 2007; 338: 237-250.

17. Croley TE, Luukkonen CL. Potential effects of climate change on ground water in Lansing, Michigan. J Am Water Resour As. 2003; 39 (1): 149–163.

18. Allen DM, Mackie DC, Wei M. Groundwater and climate change: a sensitivity analysis for the Grand Forks aquifer, southern British Columbia, Canada. Hydrogeol J. 2004; 12: 270-290.

19. Dragoni W, Sukhija BS, Climate Change and Groundwater, Geological Society, London, Special Publications, 2008; 288: p. 1-12.

20. Grand River Conservation Authority (GRCA), Low water response - areas of concern - Mill Creek.,

http://www.grandriver.ca/LowWater/mill.cfm, 2002.

21. Grand River Conservation Authority (GRCA), state of the watershed report: Background Report on the Health of the Grand River Watershed 1996-97. Cambridge, Ontario. 1998; p. 143.

22. Wood AW, Leung LR, Sridhar V, Lettenmaier DP.: Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs, Climatic Change, 2004; 62: 189-216.

23. Xu Z, Yang ZL. An Improved Dynamical Downscaling Method with GCM Bias Corrections and Its Validation with 30 Years of Climate Simulations. J Climate. 2012; 25: 6271-6286.

24. Diaz-Nieto J, Wilby RL. A comparison of statistical downscaling and climate change factor methods: impacts on low flows in the River Thames, United Kingdom. Climatic Change. 2005; 2(3): 245-268.

25. Anandhi A, Frei A, Pierson DC, Schneiderman EM, Zion MS, Lounsbury D, et al. Examination of change factor methodologies for climate change impact assessment, Wat Res Res. 2011; 47(3): p. W03501.

26. Waterloo Hydrologic Inc. (WHI). User’s manual of Visual HELP, 2001; p. 335.

27. Brooks RH, Corey AT, Hydraulic properties of porous media. Hydrology Papers, No. 3, Colorado State U., Fort Collins, Colorado, 1964; p. 27.

28. Schroeder PR, Dozier TS, Zappi PA., McEnroe BM, Sjostrom JW, Peyton RL. The hydrologic evaluation of landfill performance (HELP) model: Engineering documentation for version 3. Environmental Protection Agency (EPA), 1994; p. 168.

29. Berger K, The hydrologic evaluation of landfill performance (HELP) model, Institute of Soil Science, Hamburg, Germany, https://www.geo.uni-hamburg.de/en/bodenkunde/service/help-model.html; 2014.

30. Presant EW, Wicklund RE, The soils of waterloo county, Report Nº 44 of the Ontario Soil Survey, Department of Soil Science, University of Guelph and The Ontario Department of Agricultural and Food, 1971; p. 104.

ارزیابی اثر تغییر اقلیم بر تغذیه آب‌های زیر زمینی برای خاک‌های مختلف مورد مطالعاتی : منطقه گوالف حوضه آبریز گراند ریور انتاریو- کانادا

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مقدمه: گرمایش جهانی و تغییر اقلیم به عنوان یکی از مهم‌ترین پدیده‌های گسترده قرن بیست و یکم بر منابع آبی جهان تاثیر گذاشته است. افزایش درجه حرارت، باعث تغییر در بارندگی و تبخیر در تمام مناطق جهان گردیده و در نتیجه تغییر در کیفیت و کمیت منابع آب‌های سطحی و زیر زمینی را باعث شده است.

مواد و روش‌ها: سه مدل گردش عمومی آب و هوا بنام‌های GISS ، GFDM و CCC و آمار پایه یک دوره سی ساله (۱۳۷۳-۱۳۴۴) برای بررسی اثر تغییر اقلیم بر نرخ تغذیه آب‌های زیر زمینی برای سه نوع خاک بین سال‌های ۱۳۹۰ تا ۱۴۳۰ (۲۰۱۰-۲۰۵۰) در منطقه گوالف در حوضه آبریز گراند ریور در ایالت انتاریو کانادا مورد استفاده واقع شده است.

بحث و نتیجه گیری: نتایج به‌دست آمده نشان می‌دهد که اگر چه در فصل تابستان تبخیر افزایش و نفوذ کم می‌شود ولی در فصل زمستان به دلیل شرایط یخ و سرما، میزان نفوذ کل افزایش می‌یابد. نتایج نشان دهنده افزایش متوسط ۱۰٪ (۷٪ برای مدل CCC، ۱۰/۶ درصد برای مدل GISS، و ۱۲ درصد برای مدل GFDL) در آینده می‌باشد.

کلمات کلیدی: آب‌های زیرزمینی، تغییر اقلیم، حوضه آبریز گراند ریور، مدل Visual HELP، مدل‌های GCM