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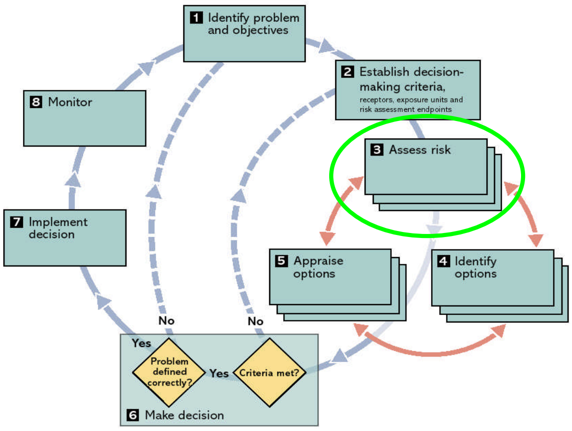
The Isle of Man Climate Change Scoping Study

Technical Paper 10

Climate change and water resources on the Isle of Man



Report for
Martin Hall, DLGE, Isle of Man Government

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Report prepared by
ICARUS: Irish Climate Analysis and Research Units

Approved by
John Firth, Managing Director

acclimatise
6 Nursery End
Southwell
Nottinghamshire
NG25 0BY

T: +44 (0) 1636 812868
F: +44 (0) 1636 812702
E: enquiries@acclimatise.uk.com
W: www.acclimatise.uk.com

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CLIMATE CHANGE:

Indicators, Scenarios and Impacts for the Isle of Man

A scoping report prepared for the Isle of Man
on behalf of
acclimatise

Prepared by

ICARUS
Irish Climate Analysis and Research Units

Authors:

Murphy, C., Sweeney, J., Fealy, R. and McElwain, L.

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Climate Change and Water Resources on the Isle of Man

1.0 Introduction

In comparison with much of Europe the Isle of Man is relatively well endowed in terms of water resources. The vast majority of water supply on the island comes from surface water resources with a complex system of dams and reservoirs currently in operation. In terms of groundwater, the limited permeability of the underlying geology of the island results in a distinct lack of subsurface water resources in comparison to Ireland and Britain. While much of the island is underlain by porous glacial drift, the impermeable nature of many rock groups and sub-soils such as the Manx group and deposits of diamicton mean that there are few available deep groundwater resources. Although there are substantial deposits of Carboniferous Limestone on the island it is not sufficiently well bedded to allow the development of karstic aquifers. Therefore the island relies heavily on surface water resources to meet water demand. In terms of water supply the island can be divided into five water supply zones. These include the Balladawne zone in the southwest, serving urban areas such as Port Erin and Port St. Mary, the Glen Maye zone in the west serving areas such as Glen Maye and Peel, the Sulby supply zone serving the majority of the population in the north and west of the island, the Ballure supply zone in the east and the Glencrutchery supply zone in the east and southeast, servicing major urban areas such as Douglas. In total the Water Authority operates ten upland impounding reservoirs ranging in capacity from under 1 million gallons to over 1,000 million gallons (IOM Water Authority, 2005).

While current water resources are capable of meeting present demand, surface water resources are likely to be significantly affected by climate change (IPCC, 2001). Therefore, given the reliance on surface water on the island there is a requirement to assess the impacts of climate change on water resources for the Isle of Man. This research will provide a first pass assessment of the impacts of climate change on water resources in the Isle of Man. The main aims of the research include:

- To assess the annual and seasonal changes in effective runoff for the Isle of Man.
- To determine the spatial distribution of change in order to highlight the areas most at risk from water shortages and flooding.
- To assess the impact of climate change on water supply and resource management, with particular emphasis on water quality and flood management.

1.1 Climate Change and the Hydrological Cycle

The global hydrological cycle describes the movement of water between the earth and atmosphere in different states. In its most simple form it accounts for the processes of evaporation, precipitation and the runoff of any surplus water over the land surface. On a smaller scale it is possible to view the catchment hydrological cycle as a more in-depth model, involving the processes of interception, storage, runoff and streamflow.

On every scale, changes in global climate are likely to have significant impacts on hydrology and water resources, with increased energy resulting in an intensified hydrological cycle. Given the importance of precipitation and evaporation as driving forces, any changes in these primary processes may have considerable knock on effects for the rest of the hydrological cycle, such as changes in effective runoff and the variability of streamflow, with consequences for water supply and the magnitude and frequency of extreme events.

In terms of large-scale projected changes to the inputs of the hydrological cycle, GCMs simulate an increase in annual precipitation in high and mid-latitudes and most equatorial regions but a general decrease in the subtropics (IPCC, 2001). The largest percentage precipitation changes over land are found in high latitudes, some equatorial regions, and south-east Asia, although there are large differences between climate models (IPCC, 2001). Changes in evaporation are largely dependent on the amount of water present and the availably energy. Increasing temperature, and the corresponding increase in the water holding capacity of air, generally results in an increase in potential evaporation. (IPCC, 2001). Although changes in the processes of precipitation and evaporation can be estimated at a global scale, both are characterised by large geographical variation. For example, precipitation can vary hugely depending on elevation and aspect, while evaporation is largely dependent on solar radiation, wind speed, land cover and soil moisture deficits.

It is not just the surface components of the hydrological cycle that show likely changes as a consequence of global warming, sub-surface hydrological processes are also likely to be altered. Gregory *et al.* (1997) demonstrated with the HadCM2 climate model that a rise in greenhouse gas (GHG) concentrations is associated with reduced soil moisture in Northern Hemisphere mid-latitude summers. Soil water resources are fundamentally important for the sustainability of certain agricultural practices as well as in the timing of important hydrological events such as groundwater recharge and the generation of runoff. 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 (IPCC, 2001). In terms of groundwater resources, increased winter rainfall—as projected under most scenarios for mid-latitudes—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 (IPCC, 2001).

1.2 Previous Work in Ireland and Britain

Although little work has been conducted in assessing the impacts of climate change on effective runoff and water resources specifically for the Isle of Man, a number of studies have been reported for Britain and Ireland. Arnell (1992, 1996), Arnell and Reynard (1993) and Pilling and Jones (1999) have considered the impacts of climate change on runoff over the entire area of Britain. Each of these studies involved running a rainfall-runoff model for grid cells rather than for individual catchments in order to highlight the spatial distribution of impacts. Although the grid squares employed do not represent actual catchments, such studies allow changing patterns of annual and seasonal runoff to be considered and provide a valuable starting point for further research. For example, Pilling and Jones (1999) employed a physical process-based hydrological model to simulate effective runoff for 10 km x 10 km grids covering the UK under current baseline and future climate scenarios. The climate change scenarios were constructed from the Hadley Centre's high-resolution equilibrium GCM for 2050 and transient GCM for 2065, with the simulated changes in precipitation and potential evapotranspiration applied to the baseline climatology. The authors found that changes in effective runoff for winter and summer show an increase in seasonality under both scenarios, with winter runoff seen to increase most in the north of Britain while summer runoff was shown to experience major reductions over much of England and Wales Therefore an accentuated imbalance in effective runoff between north west and south east was suggested (Pilling and Jones, 1999).

A similar approach was conducted in Ireland by Sweeney *et al* (2003). In this work the land area of Ireland was also represented by 10 km x 10 km grid squares with each grid being adopted as the basic hydrological unit. Output from HadCM3 was downscaled for 560 precipitation stations and 70 temperature stations. Polynomial regression was then used to redistribute the downscaled values for each grid cell. The particular run concerned (HadCM3GGa1) was based on historical increases in greenhouse gases from 1860 to 1990 and then partly on the emission scenario IS95a. This involved a 1% per annum rise in radiative forcing and is characterised as a middle of the road scenario. Three sets of hydrological simulations were carried out, comprising a baseline 1961-90 and two future scenarios, 2041-2070 and 2061-2090. Results suggested that under both future scenarios widespread reductions in annual runoff were likely, especially in the east of the country. Increases in winter runoff were suggested for large parts of the west of the island while all areas experienced substantial decreases in summer runoff (Sweeney *et al*, 2003).

1.3 Research Outline

The primary aim of this research is to assess the impacts of climate change on effective runoff for the entire land surface of the Isle of Man. A grid-based approach akin to that used by Sweeney *et al* (2003) for Ireland and Pilling and Jones (1999) for Britain is utilised. The employment of such a methodology was driven by two major factors. Firstly, reliable and naturalised streamflow data for individual catchments within the Isle of Man are sparse with only three streamflow observations a year being made for some catchments. This is not sufficient for calibrating and validating a rainfall-runoff model. Secondly, the potential to simulate the entire land area of the island using a grid-based approach offers the ability to identify spatial variations in effective runoff.

There are also disadvantages to adapting a grid-based approach. While it may provide a finer spatial representation of land surface properties than a catchment based approach, the accurate representation of groundwater, lake and reservoir storage presents problems. Streamflow records are required to derive some of the parameters relating to these and are obviously not available for grid squares (Charlton and Moore, 2003). It is therefore necessary to simplify the representation of some of the storage terms in the rainfall-runoff model. However, despite this, Charlton and Moore (2003) have shown that it is possible to gain some insight as to likely spatial and temporal changes in storage as a result of climate change.

When simulating the impact of climate change on water resources previous work has shown that characteristics such as soil type, porosity, bedrock and aquifer potential all influence the response of the hydrological system to climate change (Murphy *et al*, 2005). In order to take account of this 31 5 km x 5 km (25 km^2) grids were used to represent the land surface of the Isle of Man so as more detail could be incorporated into land surface parameterisation. These grids are shown in figure 1.1 below. In order to simulate effective runoff monthly data for precipitation and evapotranspiration were used to run a physical, process-based rainfall-runoff model for each hydrological grid. Squares were assigned individual values for each of the hydrological parameters on the basis of information derived from digital map sources. Given the lack of reliable streamflow data in the Isle of Man, baseline simulations were validated for surrogate catchments in Ireland that show a similarity to the hydrological characteristics in the Isle of Man. In order to calculate future simulations of runoff, the rainfall-runoff model was forced with pattern scaled output from the HadRM3 model as described in technical paper 4 on Future Climate Change Scenarios. Hydrological simulations were carried out for three future time horizons, the 2020s (2011-2040), the 2050s (2041-2070) and the 2080s (2071-2100) under the A1F1, A2, B1 and B2 scenarios. While simulations were carried out for each only the A2 scenario is reported. The remainder of the runs are used to provide maximum and minimum ranges of likely change. Changes in future runoff are assessed through comparison with the 1961-1990 control period.

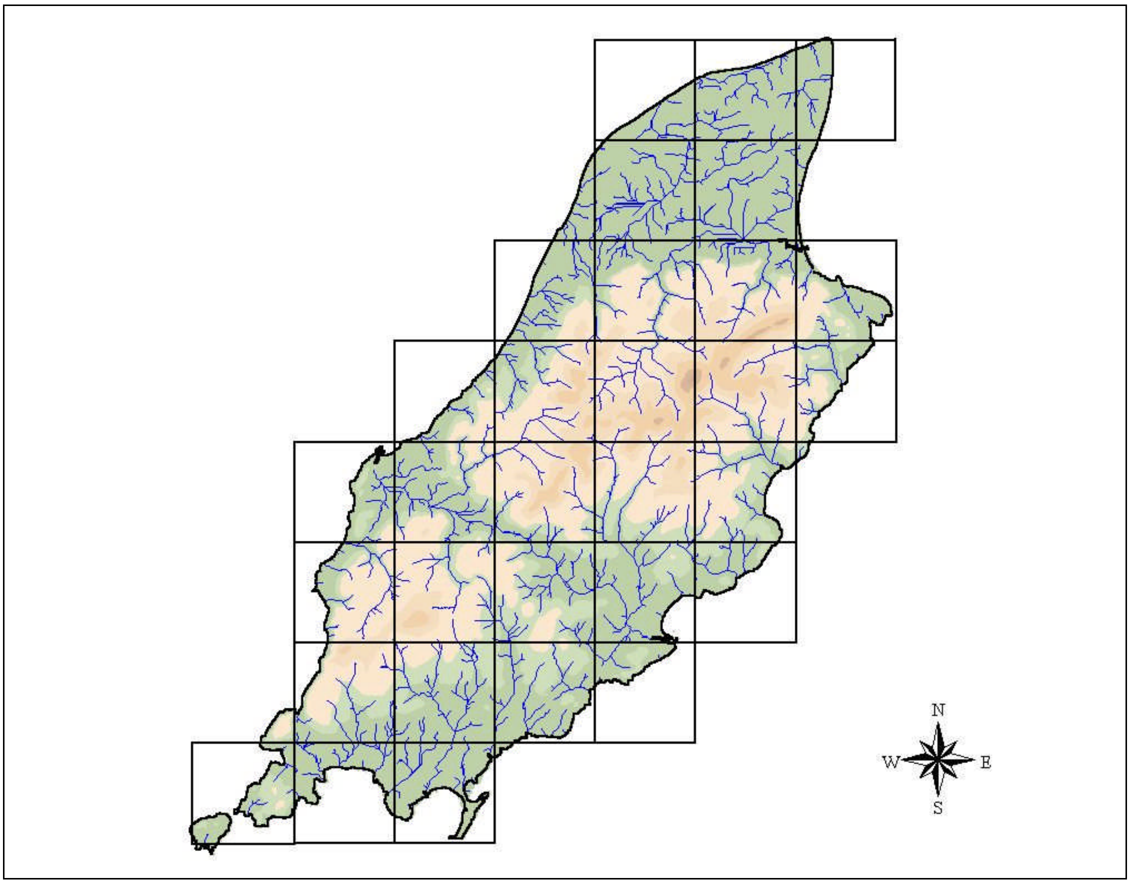


Figure 1.1 Location of grid squares used for simulating the percent change in effective runoff relative to the land surface of the Isle of Man

2.0 The Hydrological Model

The rainfall-runoff model employed is HYSIM (Manley, 1993). This is a conceptual rainfall-runoff model, which uses rainfall and potential evaporation data to simulate hydrology, using parameters that define the river basin and channels in a realistic way. Although spatially lumped and hydrologically conceptual in nature, the majority of model parameters can be measured from physical reality. The model is built around two sub-routines; the first of these simulates land surface hydrological properties while the second simulates hydraulics. The complete flow diagram of the structure of the model is given in Figure 1.2. In relation to the hydrology, seven natural stores are represented. These include snow storage, interception storage, the upper soil horizon, the lower soil horizon, transitional groundwater, groundwater and minor channel storage.

To gain an insight into the functioning of the model it is beneficial to take a more in-depth look at how these stores function and interact. Given the small amount of snowfall recorded in the Isle of Man this store is not utilised. Interception storage represents the storage of moisture by the vegetation canopy. Evaporation accounts for losses from this store. Any moisture in excess of storage, determined by vegetation type, is passed on to the upper soil horizon. The upper soil horizon represents the moisture held in the upper (A) horizon or topsoil and has a finite storage capacity equal to the depth of the A horizon multiplied by its porosity. A limit on the rate at which moisture can enter the upper soil store is applied based on its potential infiltration rate. Losses are met by evaporation, interflow and percolation to the lower soil horizon. Evaporation is controlled by the forces of capillary suction, while interflow is a function of the effective horizontal permeability of the soil layer. The lower soil horizon represents moisture below the upper horizon but still within the rooting depth of vegetation. Again evaporation and interflow account for losses from this store as well as percolation to groundwater. The transitional groundwater store is an infinite linear reservoir, which serves to represent the first stage of groundwater storage. This store has greatest importance in catchments with permeable geologies with losses being controlled by a discharge coefficient. Groundwater is also represented as an infinite linear reservoir, assumed to have a constant discharge coefficient. The final conceptual store represented by HYSIM is minor channel storage. This component represents the routing of flows in minor streams and ditches. A full list of model parameters is provided in Appendix 1.1.

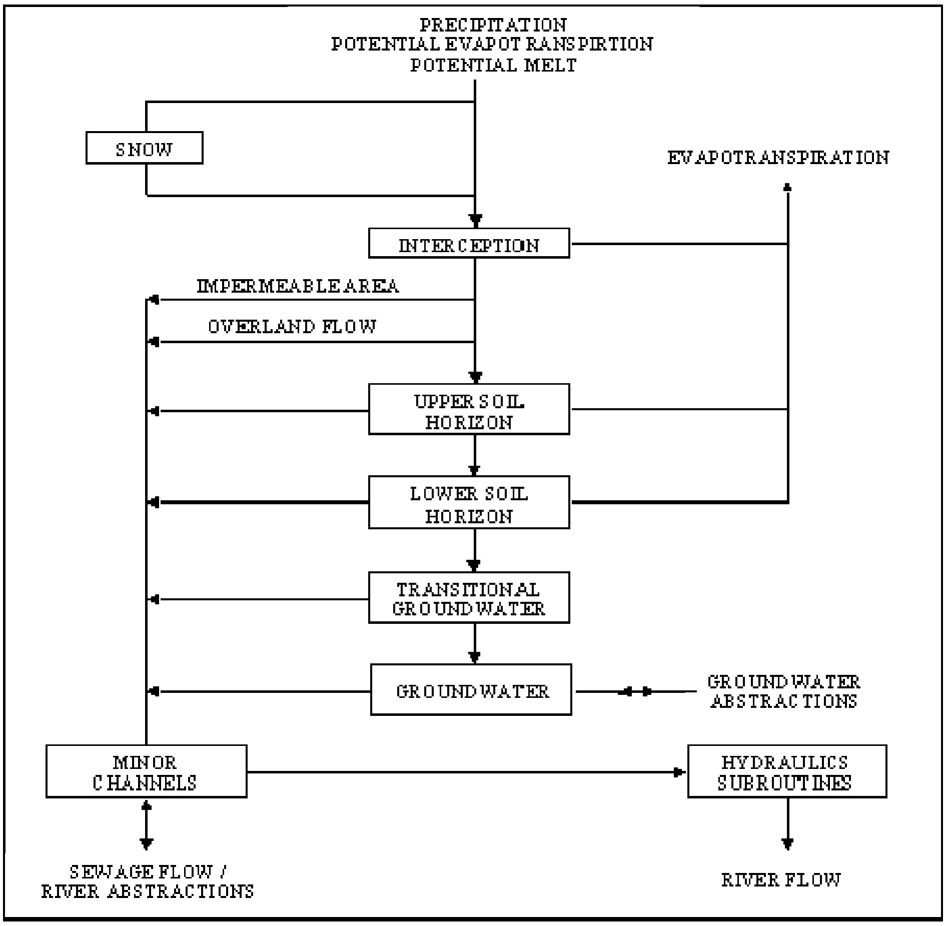


Figure 1.2 HYSIM model flow diagram

2.1 HYSIM Parameterisation

HYSIM has been designed to enable quantitative values for each of the model parameters with many being derived from analysis of soil type. Within the Isle of Man, soil properties are closely related to glacial deposits and bedrock geology. Figure 1.3 shows the distribution of glacial drift throughout the island. Within the northern lowlands deposits of sand, gravel and mud are predominant, while much of the remainder of the island, including the central uplands are covered with deposits of sand, gravel and diamicton. The latter is a poorly sorted boulder clay with a low porosity. Fluvial deposits and peat are also common in many of the valleys.

Figure 1.4 provides a geological summary of the island. The predominant rock types within the island include quartz in the northern lowlands with the majority of the remainder of the island occupied by the Manx Group. The Manx Group is comprised of poorly bedded sandstones and mudstones and along with quartz both can be characterised as relatively impermeable. As a consequence, soils in the Isle of Man vary from loamy sands to peaty loams with many of the different textural classes in-between. There are thirty-two different soil sub-categories associated with five soil categories. The five are, soils associated with slates, flagstones and shales, soils associated with limestone, soils associated with Peel sandstone and Neb gravels, soils associated with glacial deposits and soils associated with peat deposits.

In order to obtain soils data for each grid square covering the land surface of the island, individual grids were used to extract information on glacial drift and bedrock geology. Once information was obtained it was used to estimate a soil texture for each grid. Manley (1993) provides parameter values related to each soil texture, with these being used as the parameter values for each grid square.

In relation to land-use parameters HYSIM requires information on interception storage, the rooting depth of vegetation and the impermeable proportion of each grid square. Land use within the island can be broadly classified into seven major categories. These include urban areas, arable land, pasture, forests (including shrub lands and natural vegetation), peat bogs, inland water bodies and areas with little or no vegetation. In order to derive values for the land-use parameters within HYSIM the CORINE land use database was used to assess the coverage of different land use types within each grid. Depending on the proportion of each land use type within each grid cell, default values relating to different land-use types were derived from Manley (1993).

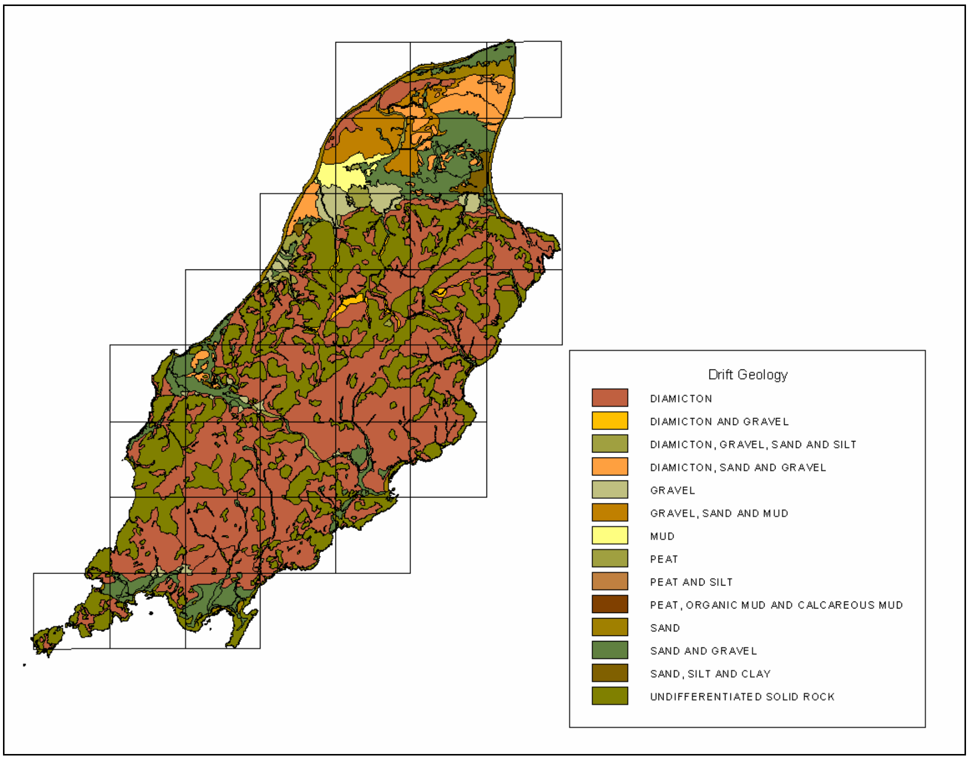


Figure 1.3 Drift Geology of the Isle of Man

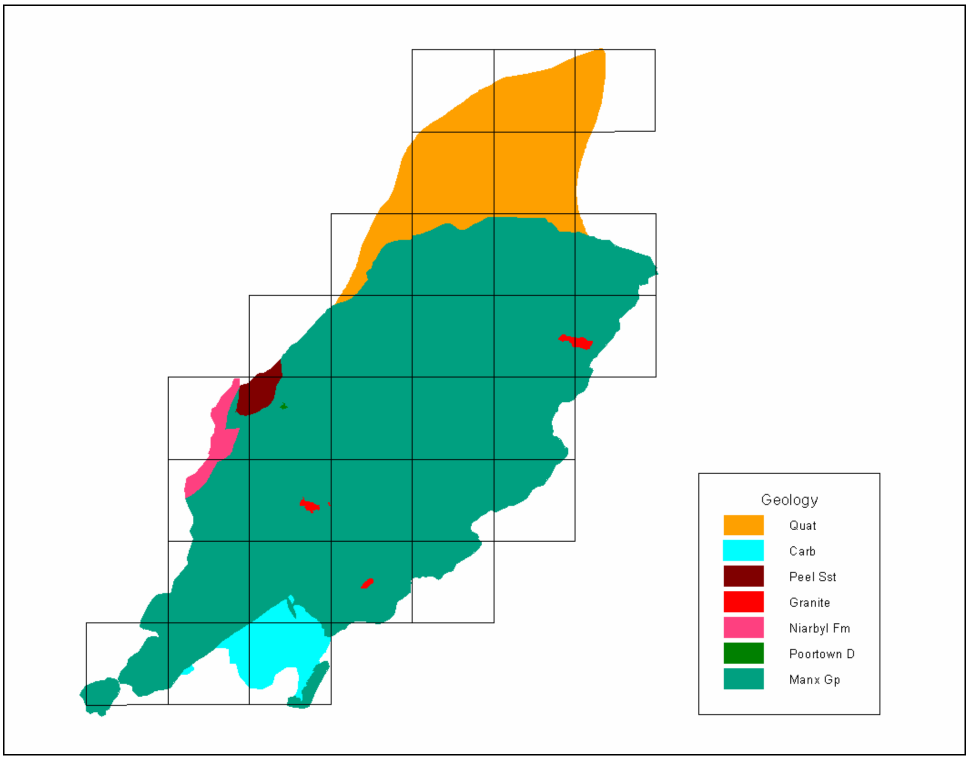


Figure 1.4 Geological Summary of the Isle of Man

In terms of groundwater the grid based approach used in this study presented some problems for the representation of groundwater. These were anticipated but since this research aims at providing a first pass study on changes in effective runoff for the entire land area it was necessary to make some simplifying assumptions. HYSIM would normally be applied to a catchment or a number of sub-catchments with the groundwater parameters derived from analysis of observed records of streamflow. During a dry period, river flows are usually dominated by groundwater, and the recession of flow in the river over time is affected by aquifer characteristics. A recession coefficient determined by hydrograph analysis integrates these aquifer characteristics. For the grid-based approach adapted in this study it was not practical to do this. Charlton and Moore (2003) carried out a sensitivity analysis on HYSIM parameters in order to determine the sensitivity of the model to changes in the groundwater recession coefficient. This showed that the value assigned to the recession coefficient was significantly less critical over relatively long periods of thirty years or more. Murphy *et al* (2005) applied HYSIM to a suite of catchments in Ireland and found that the groundwater recession coefficient could also be related to the water holing capacity of the underlying bedrock. Therefore a simpler approach was adopted by assigning each square with a groundwater reservoir and using the underlying geology to estimate the groundwater recession coefficients. Other groundwater parameters within HYSIM include the proportion of the catchment with no groundwater and the ratio of contributing catchment area to surface catchment area. These were also defined based on the water holding capacity of the underlying geology. For example, grid squares underlain by the Manx group were assumed to have a relatively low recession coefficient, especially were overlain by diamicton.

2.2 Validation

The process of validation is carried out to assess model performance by comparing observed and predicted flows for the same time period. Because grid squares do not represent actual catchments it can be difficult to compare simulated runoff from individual cells with observed runoff records (Pilling and Jones, 1999). Indeed in previous work of a similar nature (Arnell, 1992; Arnell and Reynard, 1993) no validation of model simulations with observed data is performed. The problem of validation is further compounded for the Isle of Man as only very limited observed records are available. However, despite this some method of validating the simulated runoff is clearly desirable.

In order to validate the simulations made by HYSIM and overcome the lack of naturalised and reliable observed data, surrogate catchments within Ireland were adopted. Previous work done by *ICARUS* (Irish Climate Analysis and Research UnitS) has used HYSIM to simulate effective runoff from grid squares covering the entire land area of Ireland (Charlton and Moore, 2003). Furthermore, the same methodology has been applied in deriving parameter values for each grid square. Therefore it was deemed that investigating the results obtained for hydrologically diverse catchments in Ireland would provide an adequate test of the robustness of the model and the parameterisation technique.

In this way HYSIM simulations were validated by comparing observed runoff for selected catchment areas with the runoff predicted for the corresponding grid squares. In total four catchments were selected for validation purposes. These are given in Table 1.1. Catchment sizes range from 646 km^2 to 2173 km^2, therefore providing a wide range of scales on which test the model.

River and Location of gauging station	Catchment Area (km^2)
Feale at Listowel	646
Suir at Clonmel	2173
Slaney at Scarawalsh	1036
Brosna at Ferbane	1207

Table 1.1 Irish catchments selected for validation

Mean monthly-observed flows for the 1961-1990 period were converted to annual effective runoff in mm by calculating the mean annual total volume of flow and dividing this volume over the catchment area to give a depth of flow. This process was repeated to provide seasonal runoff totals for summer (June, July and August) and winter (December, January and February). Grid squares that fell wholly or partially within each catchment were selected and the percentage contribution made by individual squares was used as a weighting factor in the calculation of simulated effective runoff for the catchment. Table 1.2 shows the annual observed and predicted effective runoff for each of the selected catchments under 1961-1990 conditions.

Effective Runoff	Feale	Suir	Slaney	Brosna
Simulated (mm)	1058.93	617.27	566.55	475.88
Observed (mm)	1070.69	697.00	565.63	441.82
% error	-1.10	-11.44	0.16	7.71

Table 1.2 Validation results for selected Irish catchments

From Table 1.2 it can be seen that the Feale, Slaney and Brosna all fall within +/- 10% of the observed values, with the percentage error for the Suir being just over 10%. These results are very reassuring for a number of reasons:

- The Feale and the Suir both drain upland catchments with the model producing acceptable simulations for both.
- The Slaney drains a generally low lying agriculturally rich, well drained catchment in the south east, again percentage error values are encouraging.
- The Brosna is another low-lying catchment with much natural vegetation and peat bogs and once again the model produces successful simulations.

Taking these results into consideration and given the hydrological diversity of the catchments employed for validation, a certain degree of confidence can be held in the parameterisation procedure and the hydrological simulations made for future climate change in the Isle of Man.

2.3 Simulated Changes in Effective Runoff and Water Resources

Changes in effective runoff were calculated for three future time periods on both an annual and seasonal basis with changes calculated from the 1961-1990 baseline period. For the hydrological simulations seasons are defined as winter (DJF), spring (MAM), summer (JJA) and autumn (SON). Simulations were derived for each of the scenarios considered. However, for ease of presentation only the simulations conducted using the A2 scenario will be given in the maps below. The remainder of the simulations are employed as maximum and minimum ranges in each of the graphs.

2.3.1 Annual Changes in Effective Runoff

Figure 1.5 shows the percent change in annual effective runoff for the Isle of Man. By the 2020s there is little change likely for the entire island with increases in the order of +1% to +2% shown for the central upland region. The remainder of the island shows no change by this time period. By the 2050s the same spatial variability of change is evident with both the north and the south of the island responding in a somewhat similar fashion. Reductions of –2% in annual runoff are evident for the northern lowlands and southern areas, with decreases becoming more pronounced as we move further from the central uplands. The uplands themselves show no change in comparison to the 1961-1990 baseline by the 2050s.

By the 2080s reductions in effective runoff are simulated for the entire land surface. Greatest reductions are again likely in the low-lying north of the island with reductions ranging in the order of –4% to –5%. Similar reductions are likely for parts of the south around Port St. Mary and Castletown. For much of the central uplands decreases of approximately -1% in annual runoff are likely, however, this reduction is more pronounced around the urbanised area of Douglas.

Figure 1.6 shows the average national percent change in annual effective runoff for each time period considered. National averages were calculated by averaging the response of each of the 31 grid squares. The 2020s is the only period to show a percentage increase, with increases of approximately 0.5% likely under the A2 scenario. When the remainder of the scenarios are taken into account further increases are shown with a maximum increase of +1.75% likely by the 2020s.

On a national scale, the 2050s show a reduction in effective runoff of approximately –1% under the A2 scenario with changes ranging from -0.5% to –1.75% under all the scenarios. Further reductions are likely by the 2080s with the A2 run suggesting reductions of –2.5% with simulated maximum and minimum ranges of -2.4% to –4.5%. Although the suggested changes in annual effective runoff do not appear to be large, it is important to remember that annual changes tend to hide seasonal variations and therefore the remainder of the report will contend with seasonal changes.

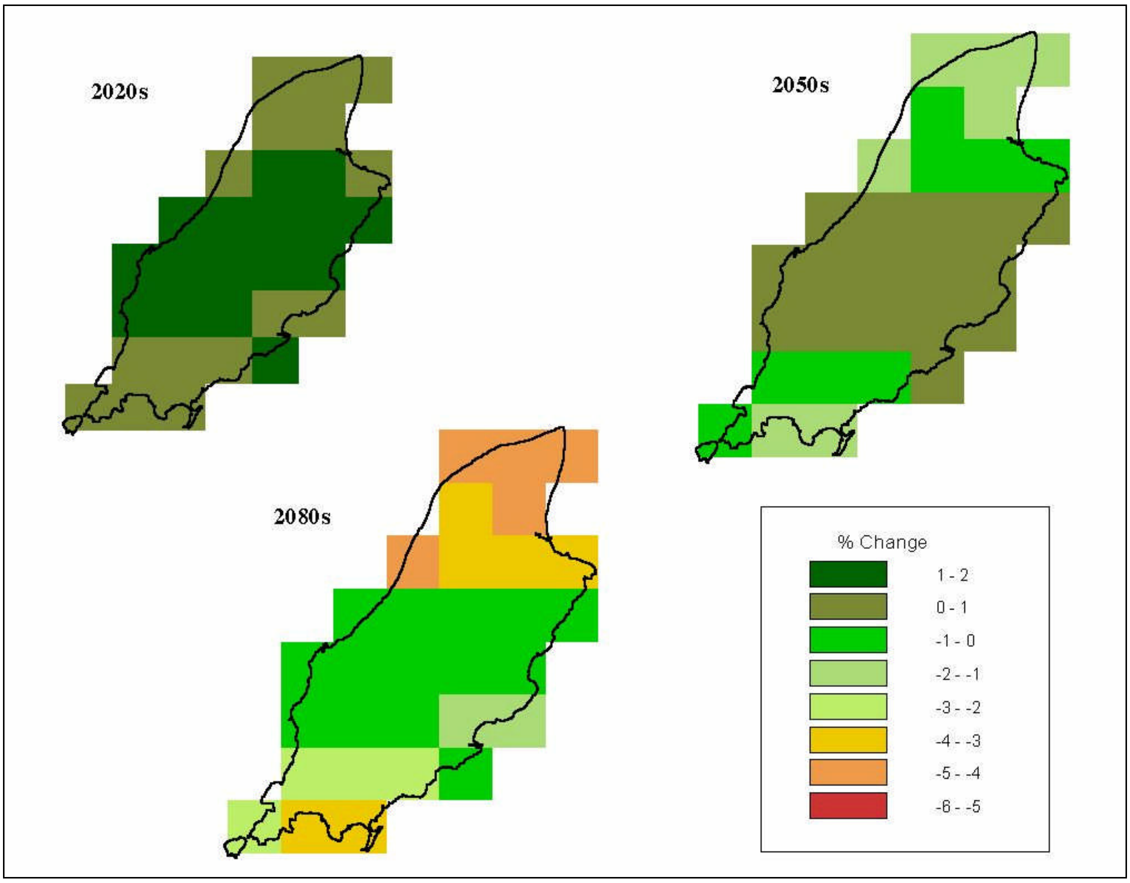


Figure 1.5 Simulated percent changes in annual effective runoff for each future time period

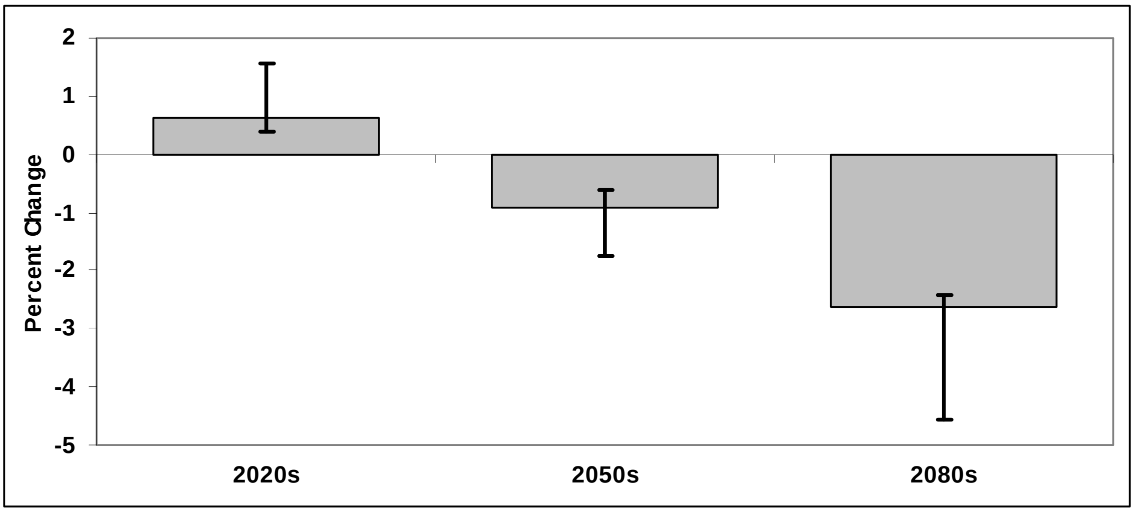


Figure 1.6 Percent change in annual average runoff for each time period

2.4 Seasonal Changes in Effective Runoff

2.4.1 Winter

Figure 1.7 shows the percent change in winter runoff for the three time horizons considered. By the 2020s an increase is simulated for over 77% of grid squares. These increases range from +1% to +13%. Greatest increases are suggested for the urbanised Laxey area. In the central uplands increases in the order of +4% to +5% are simulated while no change is likely for the northern lowlands by this time. The majority of grid squares in the south show marginal increases of +1 to +2%.

By the 2050s greater increases in effective runoff are likely with over half of the modelled grid cells suggesting an increase of +8% to +9%. The spatial variability of change between the uplands, north and south remains apparent with the majority of these cells located in the central uplands. On average, the grid cells located in the north show an increase of around +5%, while grids to the south suggest increases in the order of +7%. Greatest increases are again evident for the urban areas on the east coast with increases of up to +18% likely for the grid cells around Douglas and Laxey.

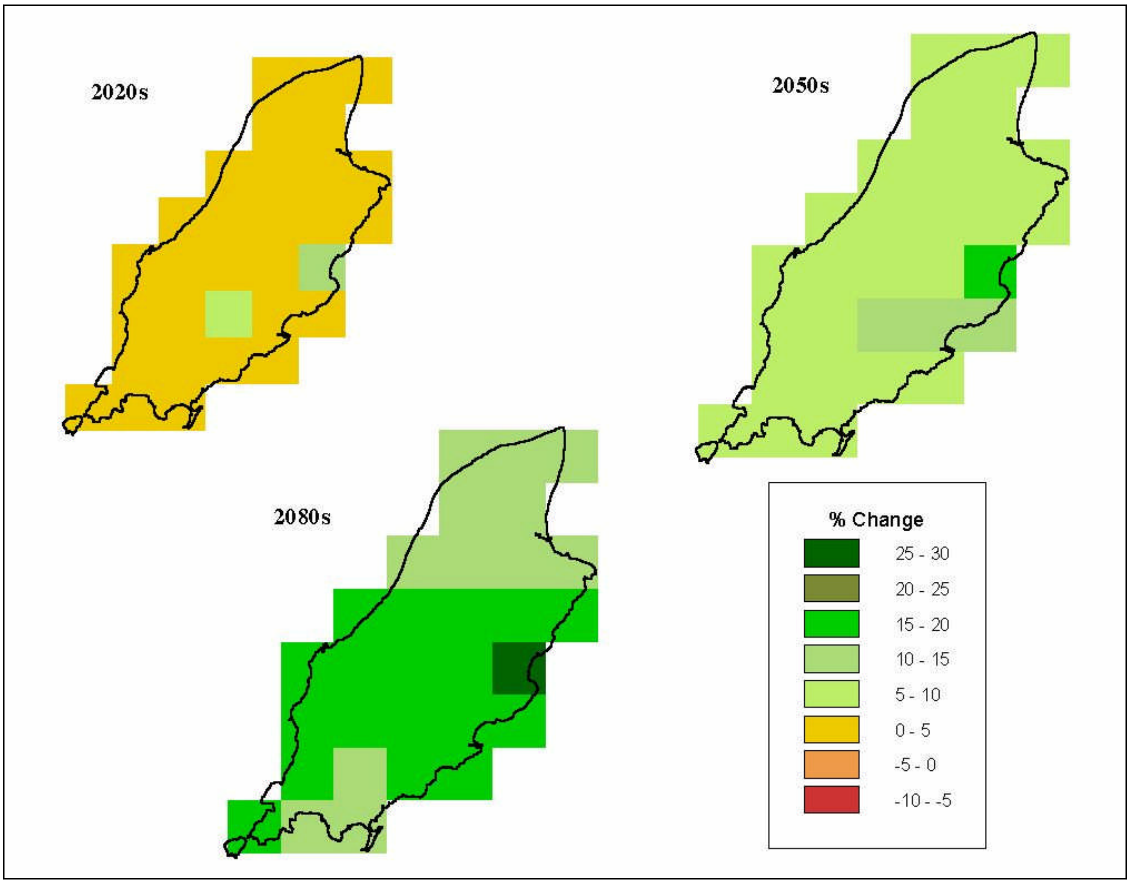


Figure 1.7 Simulated percent change in winter effective runoff for each future time period

Increases in effective runoff are likely to continue into the 2080s with all grids squares showing increases of over +13%. Again the central uplands suggest the greatest increases with changes of +16% to +18% simulated in comparison to the 1961-1990 period. As with the other time periods for winter the smallest changes are evident for the northern lowlands with increases of approximately +13% likely by the 2080s. By this time there is less of a variation in change between the central uplands and the south with increases ranging from +15% in the upland areas to +14% in southern areas around Castletown and Port St. Mary.

2.4.2 Spring

Figure 1.8 shows the percent changes in spring effective runoff for each time period. By the 2020s both increases and decrease are simulated. When the entire island is considered just over half of the cells show an increase or no change from the baseline period, with the remainder suggesting decreases in spring runoff by the 2020s.

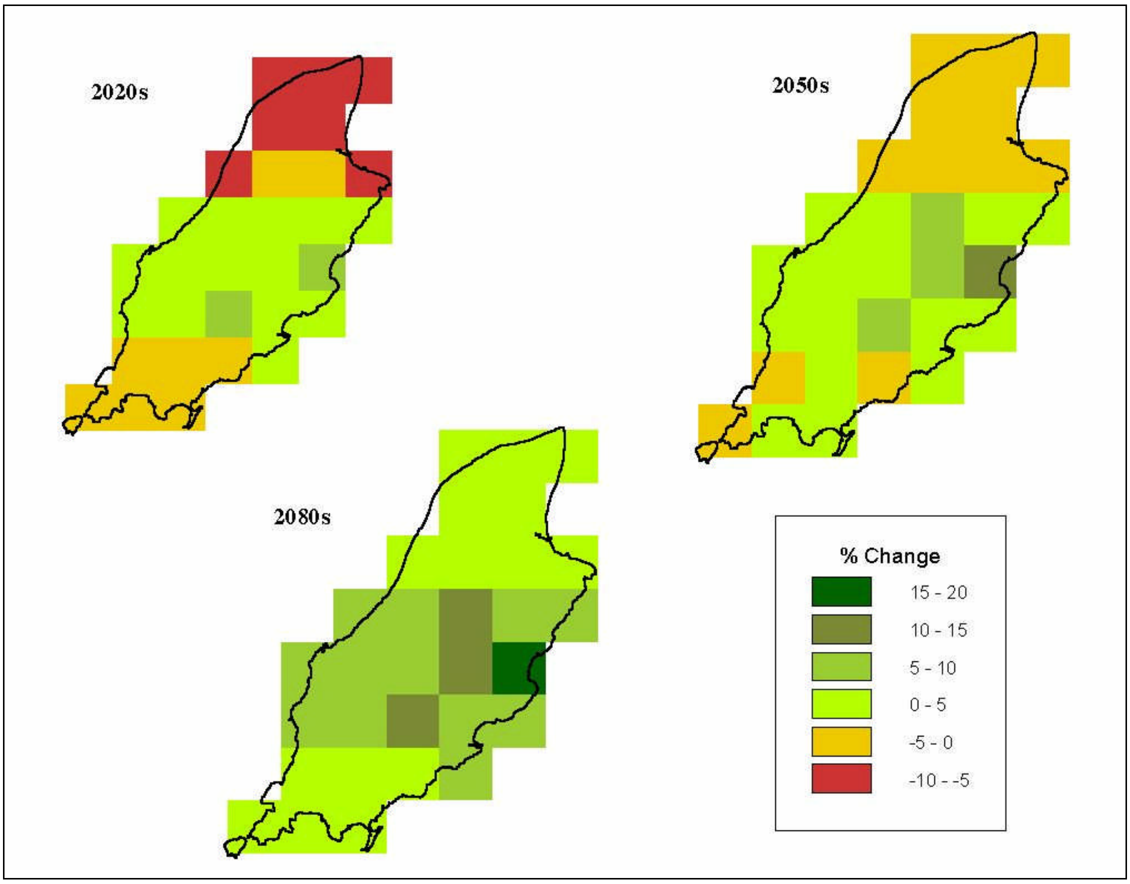


Figure 1.8 Simulated percent change in spring effective runoff for each future time period

Again there is a distinct spatial variation in changes with decreases simulated for the lower lying areas in the north and south of the island. To the north decreases are greatest with reduction of between −5% and −8% simulated for all grid cells in this region. To the south decreases are not as pronounced with simulations returning decreases of −3% to –4%. Within the central uplands increases are evident for the majority of grid squares. However, some variation within this region also emerges with the eastern coast from Kirk St. Michael to south of Peel showing 0 change to slight increases of 1%. Increases in the order of +5% to +8% are likely for the remaining portion of the upland region extending west.

By the 2050s less drying is evident during spring months with reductions not as pronounced as the 2020s, while increases in runoff are slightly greater. In the north reductions are still evident for all of the grid cells however in comparison with the 2020s reductions range from -1% to −5%. Reductions are also less in the south with some cells showing no change or only slight increases. In the central area marginal increases in comparison with the 2020s are evident, especially around the western coast from Douglas to Laxey. It is interesting to note that increases in runoff tend to follow an east to west gradient in the central uplands and south of the island, while such variation is not evident in the north. This feature may be related to topography with greater increases in the west associated orographic enhancement of precipitation receipts.

By the 2080s no grid shows a reduction in effective runoff. While in the 2020s and 2050s the low-lying north of the island showed decreases, by the 2080s grids in this region show no change or slight increases of up to +2% in comparison to the baseline. For the central uplands further increases are evident with simulations ranging from +9% to +16%. Increases in the south of the island are considerably less with increases ranging from +3% to +4%. The east to west gradient is also evident during the 2080s.

2.4.3 Summer

The main feature of change for the summer months (Figure 1.9) is the simulated reduction in effective runoff over the entire island. 22% of grid cells show a reduction in effective runoff of more than –50% by the 2020s. The majority of these squares are located in the low-lying northern plain. Such reductions would impact significantly on water resources in areas such as Ramsey and Sulby. Substantial reductions are also suggested for the south, with reductions in the order of –20% to –37%. The smallest reductions are evident for the central highlands, although these remain substantial with decreases of between –18% and –24% simulated. Whereas in winter and spring the smallest increases were suggested for the north of the island and the largest increases simulated for the upland areas, during the summer the largest decreases are evident for the low-lying regions while decrease in runoff are not as pronounced for the uplands.

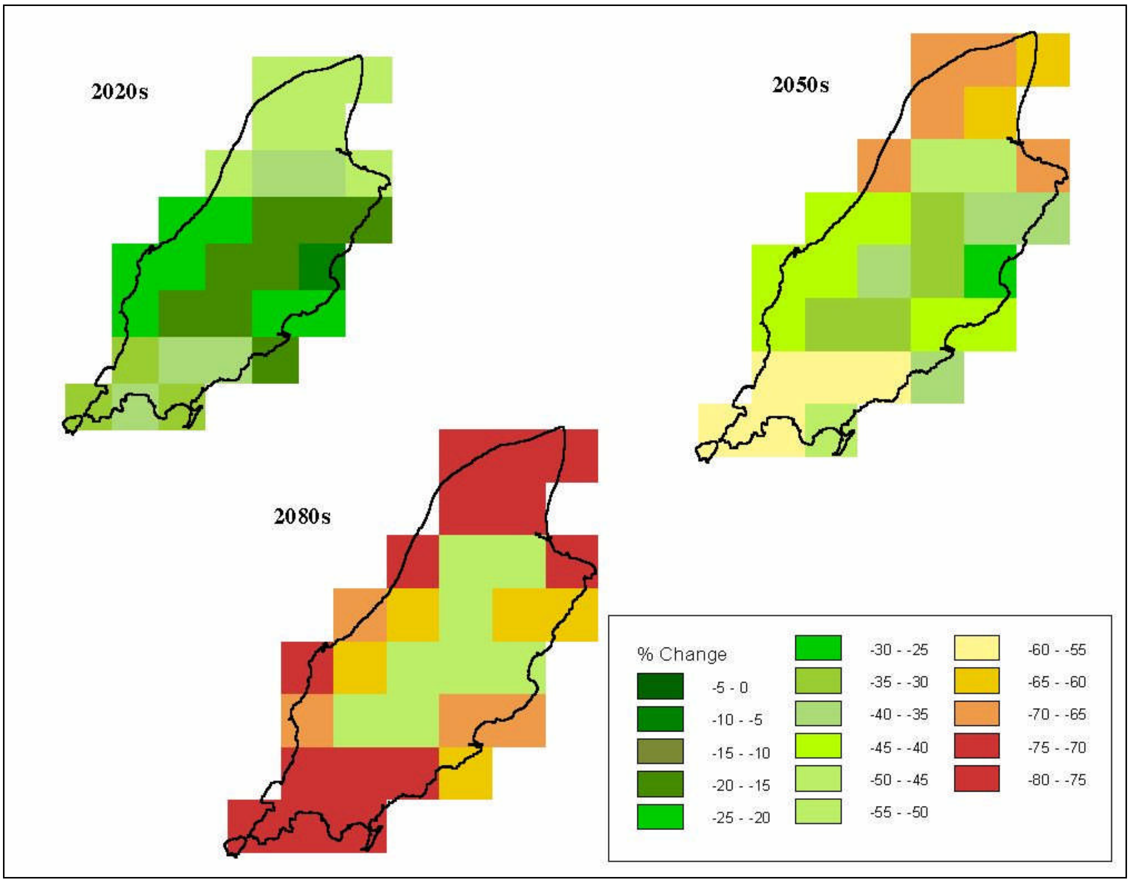


Figure 1.9 Simulated percent change in summer effective runoff for each future time period

By the 2050s further drying is evident with almost half of the simulated grid cells suggesting reductions of more than –50%. In all regions greater reductions are evident than in the 2020s. For the low-lying north decreases range from –50% to –68%, while in the south decreases in the order of –40% to –60% are likely. Further reductions are also evident for the central upland region with reductions ranging from –27% to –44%. The smallest reductions are evident in urban areas where losses from evaporation are not as high as in rural locations.

By the 2080s all grid cells suggest reductions in effective runoff of over –50% for the summer months. Interestingly, variations in reductions are largely driven by elevation and changes in land-use, with the uplands tending towards more natural vegetation and forested areas. Reductions in runoff for the agricultural lowlands of the north and south are very significant with reductions in the north of between –70% and –76%, while results in the south range from –65% to –77%. Such decreases could have serious implications for water supply in major urban areas such as Ramsey and Sulby in the north and Port Erin, Port St. Mary and Castletown in the south. Shortages could be further exacerbated given the fact that the Isle of Man relies heavily on surface water in order to meet demand. In relation to the central uplands large reductions in effective runoff are also likely with simulations ranging from –50% to –70%. Reductions of this magnitude would seriously alter the amount of water entering upland reservoirs, again providing obstacles for efficient resource management. Even within the upland region the relationship between topography and reductions in effective runoff are evident with the greatest reductions suggested for lower coastal areas in the east of this region.

2.4.4 Autumn

Figure 1.10 shows the percent change in effective runoff for the autumn months. In comparison to other seasons there is much less spatial variation in changes of runoff by the 2020s. The vast majority of grid cells show reductions with changes of between 0% and –8% suggested. By the 2050s the spatial distribution of change emerges once again with the greatest reductions in effective runoff suggested for the lowlands of the north with grid cells showing reductions ranging from –10% to –20%. Both the central highlands and the south of the island show a similar response by the 2050s with reductions in the order of –5% to –10% for both regions.

For the autumn months the most significant changes are evident for the 2080s with approximately 55% of all grids showing a reduction in runoff of –20%. Once again change can be divided into three general regions. As with the summer results the greatest decreases in autumn by the 2080s are suggested for the north of the island with reductions ranging from –30% to –40%.

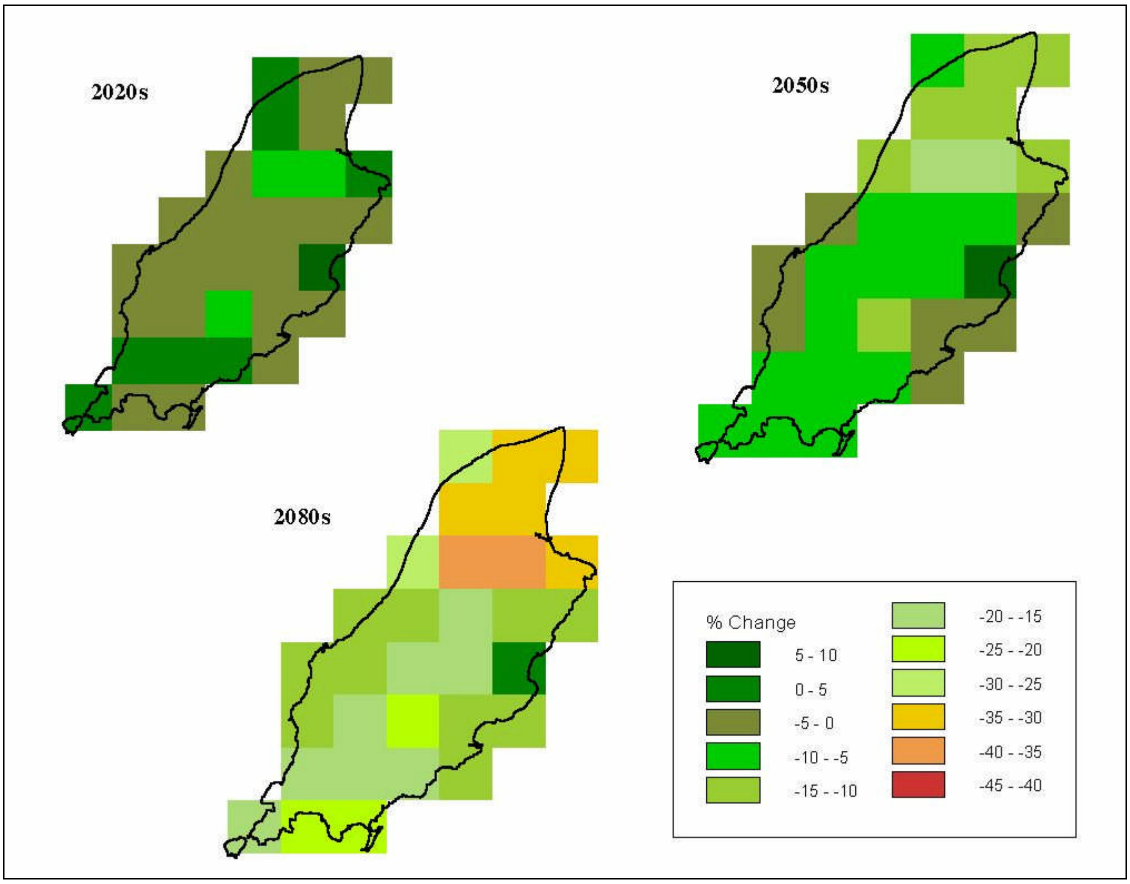


Figure 1.10 Simulated percent change in autumn effective runoff for each future time period

Substantial reductions are also evident for the south although not as pronounced, with reductions of approximately −15% to −25%. The central uplands show the smallest reductions in autumn by the 2080s with decreases in the region of −12% to −20%. Given that the autumn is an important time of the year in hydrological terms, reductions in effective runoff to the extent simulated could have consequences for the recharge of soil and groundwater storage.

2.5 National Changes in Seasonal Runoff

Figure 1.11 shows the simulated changes in effective runoff on a national level by averaging all of the 31 grid cells. Simulations obtained for the A2 scenario are shown as columns while the ranges obtained for simulations using the remaining scenarios are also provided. On a national level the most significant impact by the 2020s is the reduction in summer runoff by approximately −35% under the A2 scenario. Little change is suggested for the other seasons by this time period and there is little difference in terms of the scenarios used.

By the 2050s winter runoff is seen to increase by approximately +8% under the A2 scenario with a range of +7% to +10% likely when all scenarios are run. Slight increases are evident for spring. The most significant change by the 2050s is again the reduction in summer runoff with a national reduction of −50% suggested under the A2 run. By this time period there is also a substantial range in summer simulations depending on scenario, with simulated reductions ranging from –45% to –60%. Reductions in the order of −10% are also likely for the island as a whole by the 2050s.

By far the greatest changes in seasonal runoff on a national scale are evident for the 2080s. Winter runoff is seen to increase by +15% under the A2 scenario, with this figure ranging from +10% to +20% when all model runs are considered. For the spring only slight increases of approximately +5% are likely. Reductions in summer runoff are further pronounced by the 2080s with a national reduction of –65% suggested under the A2 run with minimum and maximum simulations producing decreases of –50% to −75%. Finally, for the autumn reductions of –20% are likely under the A2 scenario with decreases of between −10% and −30% suggested when all scenarios are run.

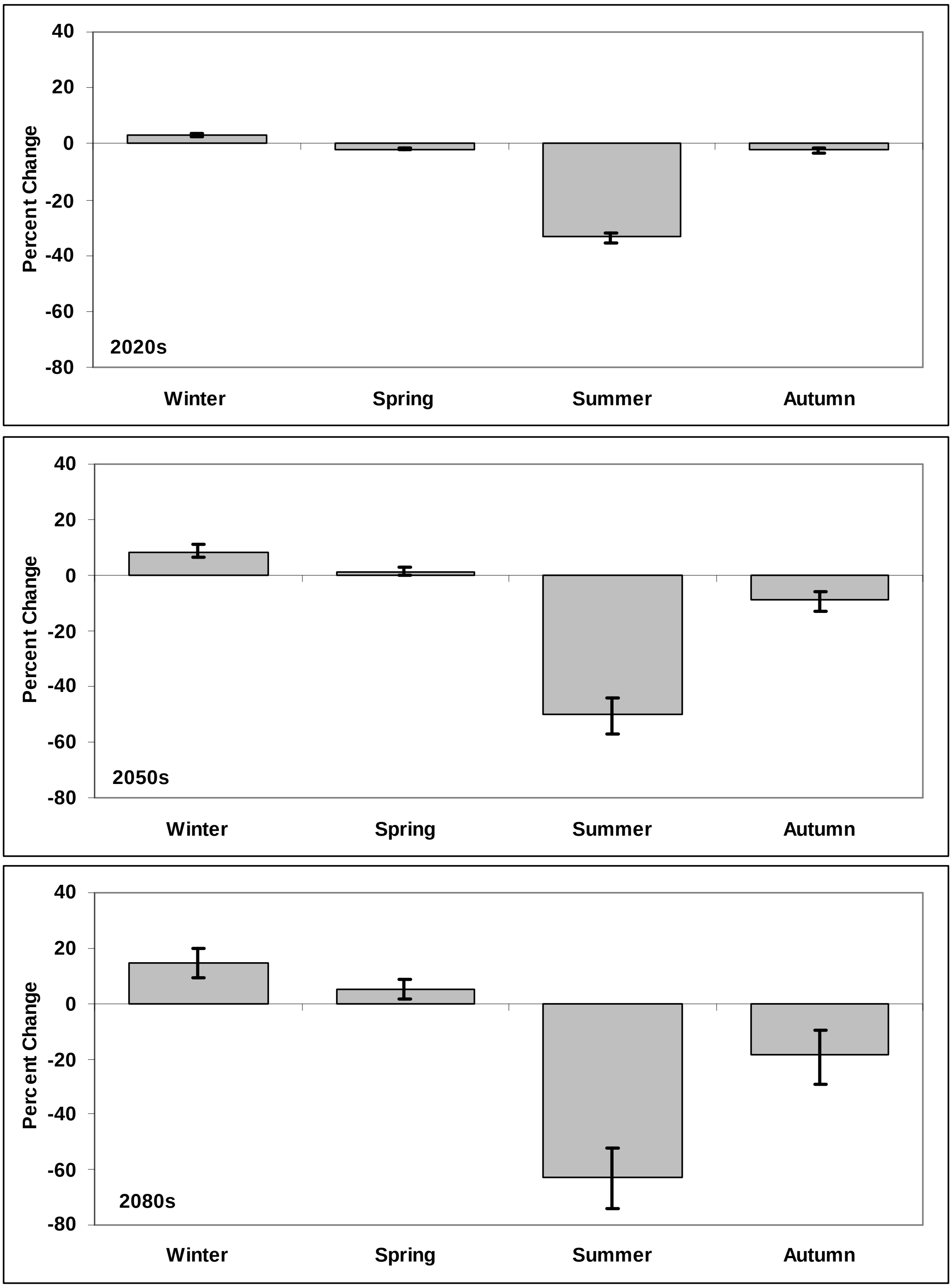


Figure 1.11 Range of likely changes in seasonal runoff under each emissions scenario considered. Columns represent the A2 scenario, while the bars represent maximum and minimum percent changes simulated by the A1F1, B1 and B2 scenarios

While the above results are based on the average changes of grid cells for the entire island, Table 1.3 shows the range of seasonal changes simulated under the A2 scenario. Maximum and minimum percent changes for the entire island are given for each season for the 2020s, 2050s and 2080s.

	2020s		**2050s**		**2080s**	
	From	***To***	***From***	***To***	***From***	***To***
Winter	0.3	13	5.6	18.7	13	26.8
Spring	-8.3	8.4	-5	11.8	-0.4	16.7
Summer	-8.2	-54	-27.6	-68.9	-51.8	-77.4
Autumn	-8.9	9.9	-18.8	6.1	-0.3	-29.5

Table 1.3 Range of simulated percent change in seasonal runoff for grid cells for the entire island for each future time period

3.0 Implications of Climate Change for Future Water Supply and Water Resource Management

By far the most significant results in terms of water supply are the reductions likely in summer and autumn effective runoff. Such reductions could be particularly problematic given the reliance on surface water resources for water provision in the Isle of Man. Reductions of the magnitude suggested for the summer months, especially for the 2050s and 2080s could result in prolonged drought conditions and low water levels in many of the island's reservoirs. Furthermore, evaporation losses are likely to increase during the summer and autumn months and will also have a significant effect on reservoir yields. Unfortunately there is limited potential in developing groundwater resources due to the limited number of aquifers and consideration might be given to utilising the increases in runoff during the winter and spring by storing water until required. Attention should also be paid to demand management. The low-lying areas of the north and south of the island are the predominantly agricultural regions and it is here that the greatest reductions in effective runoff are simulated. Therefore, there could be emerging demands on water resources with the likelihood that irrigation may be required to sustain the cultivation of some crops in the summer and autumn. Furthermore, current demand from all sectors is likely to increase under a warmer climate. Despite the limitations of groundwater resources in the island a number of options exist to supplement water resources during times when demand is greater than available resources. These include the raising of dams to provide additional raw water storage, the construction of new reservoirs so as to increase the proportion of the central uplands that are used for supplying water and desalinisation.

Given the importance of surface water resources a closer analysis of the response of important catchments would provide and valuable insight into future challenges facing water resources management. In doing this, the impacts of climate change on effective runoff were assessed for two strategically important catchments; the River Douglas catchment, including the River Glass which supply much of the water in the Glencrutchery supply zone and the Sulby River to the north. A Digital Elevation Model (DEM) for the island was used to extract outlines for both catchments. These outlines were then overlain on the simulated runoff grids and the values of interest were extracted and averaged for each catchment. The percent change for each catchment is provided in Figure 1.12, while the location of the catchments is given in Figure 1.13.

Once again, columns are representative of the A2 scenario, while ranges are indicative of all scenario runs. For the Douglas catchment the most significant changes in effective runoff are likely for the summer by the 2020s with reductions of approximately –25%. By the 2050s increases in winter and spring are likely with reductions of up to –40% under the A2 scenario. Decreases of approximately –15% are also likely for the autumn months. By the 2080s reductions in summer reach just over –60% with reductions in autumn approaching -20%. Increases in effective runoff for winter and spring are also substantial with increases of approximately +20% and +10% respectively.

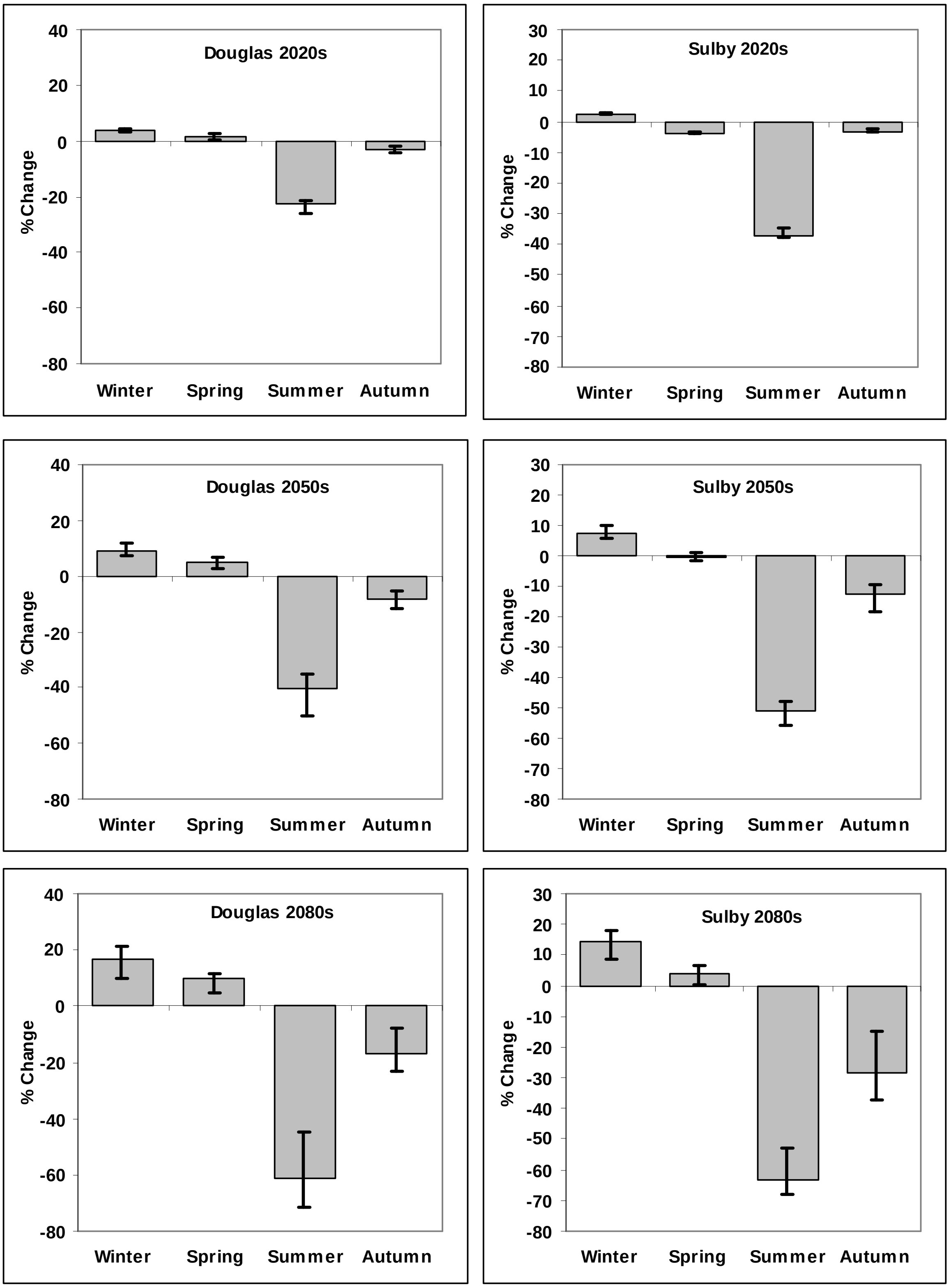
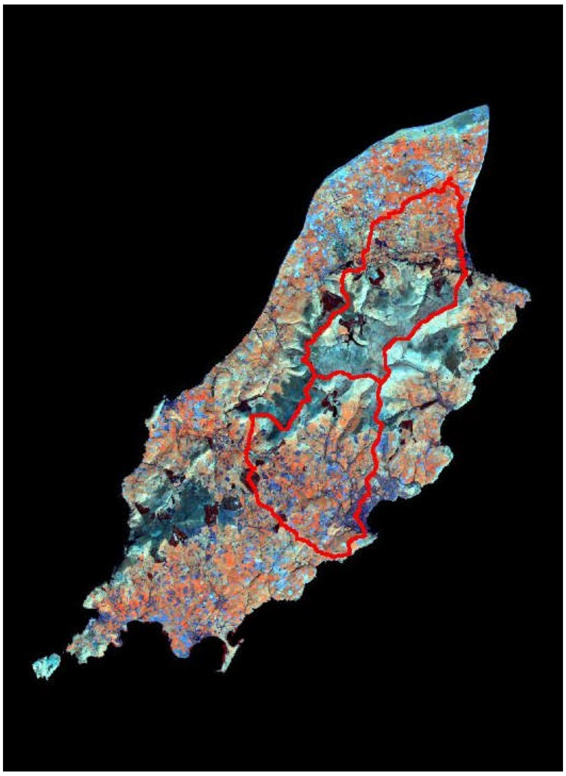


Figure 1.12 Simulated percent change in effective runoff for both the Douglas and Sulby catchments for each future time period

For the Sulby catchment reductions in summer runoff are greater given its more northerly position with reductions of –35% likely by the 2020s throughout the catchment. Little change is evident for the remaining seasons by this time period. By the 2050s slight increases are likely for the winter months, again these increases are not as large as the in the River Douglas catchment. Reductions in summer runoff by the 2050s extend to approximately −50% under the A2 scenario and substantial reductions of approximately –15% are likely for the autumn. By the 2080s reductions in winter, spring and summer are comparable in magnitude to those reported for the River Douglas. However, more severe reductions are likely during the autumn with simulations indicating decreases in the order of –30% under the A2 scenario, with a maximum reduction of –40% when all model runs are considered. While reductions in runoff are severe for each catchment during the summer and autumn, it is important to realise that reductions are least for the upland areas used for water supply. Nevertheless reductions in these areas remain substantial.



1.13 Location of selected catchments. The River Sulby catchment is located to the north, while the River Douglas catchment is located to the south.

3.1 Water Quality

Water quality is an essential component in the planning and operation of water management systems. The simulated reductions in effective runoff indicate that a number of water quality issues may arise as a result of climate change. Taking into account the scale of reductions indicated it is not unreasonable to assume that the frequency and duration of low flows will increase. This would mean that less water would be available to dilute organic effluent. While Biological Oxygen Demand (BOD) is greatly reduced by the sewage treatment process, a certain amount of flow is required to receive effluent. Therefore, if flows fall below a minimum level there may be consequences for fisheries and freshwater ecosystems. Further research is required in this area.

3.2 Flood management

Although it is not possible to comment on changes in flood magnitude and frequency, the increase in winter runoff suggested for many parts of the island are likely to have significant implications. River flooding is affected by meteorological, topographical, geological and other factors. In the Isle of Man increases in runoff for the central uplands are particularly important, as streamflow response tends to be flashy due to steep slopes, thin soils and little attenuation effects. Furthermore, modelling of the River Sulby undertaken by Bullen Consultants (2002) indicates that current flow characteristics within the catchment are affected significantly by upstream and downstream boundary conditions (i.e. the level of water in the Sulby Reservoir and the tide level at Ramsey). As these conditions are likely to be affected as a result of climate change the frequency and occurrence of flooding is likely to increase. Increased erosion is also likely to accompany increases in the magnitude and frequency of extreme events. Further research is also required in this area.

4.0 Conclusions

This is the first time that GCM predictions have been employed to model effective runoff for the Isle of Man under future climate scenarios and while there are a large number of conclusions that can be taken from the above research the main characteristics of change are provided below.

- On an annual basis the reductions in effective runoff are likely for low-lying areas in the north and south of the island, while increases are suggested for the central uplands. Greatest reductions in annual effective runoff are simulated for the 2050s and 2080s.
- Winter runoff is seen to increase for all parts of the island, especially by the 2080s with national increases in the order of +15% simulated under the A2 scenario. The greatest increases are expected to occur in the central uplands.
- All parts of the island will experience substantial decreases in summer and autumn runoff. Greatest reductions are expected in the north of the island and it is likely that the frequency and duration of low flows will increase in all areas. Reductions in runoff of the extent suggested could prove problematic for a country that relies so heavily on surface water resources.
- The magnitude and frequency of individual flood events are likely to increase. Rising sea levels may also exacerbate flooding impacts. Seasonal flooding is likely to occur over larger areas and persist for longer periods of time.
- Long-term deficits in soil moisture are likely to develop due to reductions in autumn runoff. Furthermore, groundwater levels and the amount of water entering many of the islands reservoirs are likely to be significantly reduced with decreases becoming more pronounced over time. Increases in evaporation are also likely to impact on water levels in storage reservoirs.

In terms of the impacts of climate change on hydrology and water resources there are a number of areas which future research need to be addressed. Changes in the frequency and magnitude of flood events needs to be approached on a catchment basis. Furthermore, the impacts of climate change on water quality can be specific to individual rivers and thus impacts need to be refined for 'at risk' catchments. In order to adequately meet these needs there is a requirement for reliable streamflow observations in strategically important catchments, which is presently unavailable. In terms of future water supply, the ability of individual reservoirs to deal with both increases and decreases in runoff also needs to be assessed, with impacts requiring refinement for individual catchments and water supply zones.

4.1 Caveats

Caution needs to be exercised when interpreting these results due to a number of simplifying assumptions that had to be made. Firstly modelling was conducted using monthly data to simulate effective runoff; therefore only indications of likely changes in streamflow variation and extreme events can be given. Given the lack of data for model validation in the Isle of Man it was necessary to assess the robustness and validity of both model output and methodology on surrogate catchments in Ireland. The results of model validation carried out were acceptable and it was assumed that the model performs comparatively well for the Isle of Man. This assumption is given strength as the above results are largely in line with previous work conducted in both Britain and Ireland.

In all climate impact assessments it is necessary to assume that land use will remain the same in a changed climate. Changes in land use can affect processes such as the amount of water intercepted by vegetation and evaporated as well as soil storage and structure. Furthermore it is assumed that soil types and textures will remain the same over the period of investigation. As mentioned in Chapter 3 there is a cascade of uncertainty in climate impact assessment. Impact models are also subject to uncertainty, especially in areas such as model structure and the equifinality of parameter sets (Wilby, 2005; Beven and Freer, 2001). Given the first pass nature of this assessment no account of impact model uncertainty is made.

Appendix

Soil Parameters

Parameter	Description	Estimation method [typical range]
Pore Size Distribution Index (PSDI)	*Controls soil response to capillary suction & moisture/effective permeability' relationships*	Soil hydrology Class [0.09 to 0.25]
Bubbling pressure	*Represents capillary suction when soil is dewatered*	Soil hydrology class [80 to 630mm]
Porosity	*Relative volume of pores in soil to total bulk volume of soil*	Soil hydrology class [0.4to0.55mm]
Permeability at horizon boundary	*The rate at which moisture moves between the two soil horizons*	Soil hydrology class [5to>200mm/h]
Permeability at base of lower horizon	*The rate at which moisture leaves the soil layers*	Soil hydrology class [0 to >100mm/h]
Proportion of moisture storage in upper Horizon	*Proportion of the total available soil moisture stored in the upper*	Standard value [0.3]
Interflow runoff from upper horizon at saturation	*Direct/lateral runoff from upper soil horizon*	Standard value
Interflow runoff from the lower horizon at saturation	*Direct runoff from the lower horizon*	Standard value
Saturated permeability at the top of Upper horizon	*Controls rate at which water enters the top of the upper soil horizon*	Soil hydrology class and land use [up to 1000mm/h for cultivated land]

Vegetation and land use parameters

Parameters	*Description*	*Estimation method [typical range]*
Interception storage	***The proportion of precipitation which is lost to runoff by interception by different types of vegetation***	**Between 2.0 mm (grassland/urban areas) and 10 mm (woodlands)**
Interception correction factor	*Weighted factor for ET from interception storage.*	1.1 for grassland to 1.5 for woodland
Impermeable proportion	***Proportion of each square which can be defined as being impermeable such as rocks, roads, urban areas, etc***	**0.02 for rural areas and up to 0.2 for urban**
Soil rooting depth (mm)	***Rooting depth of vegetation***	**Normally 1000mm but can be up to 5000mm**
Riparian proportion	*In swampy riparian areas ET occurs at Potential rate even if the catchment is 'dry'*	for woodland Typical value is 0.02

Groundwater parameters

Parameters	*Description*	*Estimation method [typical range]*
Discharge coefficient	*Controls the rate of water leaving groundwater storage*	Standard' value used [0.8]
Proportion of catchment without contributing groundwater		Estimated from geology
Ratio of contributing groundwater catchment to surface catchment	*Applied as groundwater and surface water catchments may not be contiguous*	Estimated from geology

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