INSTITUTIONAL MANAGEMENT AND PLANNING FOR DROUGHTS: A COMPARISON OF IRELAND AND ONTARIO, CANADA

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ABSTRACT

Severe drought conditions in 2018 prompted concerted efforts by Irish authorities to establish a formal planning process for drought risks as part of the wider national water management strategy. More than two decades had passed since Ireland had experienced a socioeconomically significant drought, but recently reconstructed long-term data have shown that drought is a much more frequent hazard here than previously thought. With climate change impacts likely to affect the temporal and spatial distribution of precipitation in coming decades, there is an ongoing need for further planning and preparation to reduce the vulnerability of the Irish water system to droughts. In this article we report results of a systematic comparison of Irish drought management plans and policies with those in southwestern Ontario, Canada, a region that shares many similar drought risk factors and management challenges but has longer established institutional practices for managing droughts. Key recommendations for Irish water managers emerging from this project include fostering a culture of water conservation among the Irish public; using catchments as the spatial unit for drought monitoring and management decisions; creation of standing drought management teams that involve and broaden key stakeholders and user groups; and further refining data collection to support planning for future challenges associated with climate change. Pursuing future opportunities for peer-to-peer learning between Irish water managers and their counterparts in other jurisdictions is a wider opportunity for developing best practices for drought management in the Irish context.

INTRODUCTION

Public policy, planning and management of precipitation-related hazards in the Republic of Ireland (RoI) have, for understandable reasons, focused primarily on mitigating risks associated with flooding, waterlogging and drainage. Droughts in 2018 and 2020 served as reminders that extended periods of low precipitation—and the associated impacts on agricultural productivity and water availability for household and municipal use—are less frequent hazards, yet nonetheless recurrent ones, that also require policymakers' attention. The need for drought risk management policies at national and local levels for both urban and rural water systems will, moreover, become increasingly important with anthropogenic climate change expected to affect the spatial and temporal variability of precipitation in Ireland in coming decades (Charlton *et al*. 2006; Hall and Murphy 2010; Nolan *et al*. 2017; Nolan and Flanagan 2020). In recognition of these needs, Irish Water (Uisce Éireann from December 2022)—the national water utility—initiated in 2020 the first ever drought management strategy as part of its larger water management plan for the RoI. As most references to Irish Water/ Uisce Éireann are for the period before it rebranded and for consistency with the published documents we refer to, we use the name Irish Water throughout the article.

In this article, we review historical, current and projected drought risks for Ireland, and summarise the current status of drought management practice and policy. We then describe existing institutional structures and drought monitoring and response practices in southwestern Ontario, Canada, an area with land use and settlement patterns comparable to those in southeastern Ireland, but with much longer institutional experience of drought management planning and practice. By combining empirical evidence of drought risks with insights from institutional experience in a comparable jurisdiction, this article identifies considerations for Irish decision makers for building greater drought resilience into evolving water management policies and practices.

DROUGHT AND LOW-WATER RISKS IN IRELAND

In Ireland, precipitation is ordinarily experienced in all months of the year and at levels such that flooding and waterlogging of land are more frequent hydrological hazards than is drought. Precipitation is unevenly distributed in spatial terms across Ireland, with the west of the country receiving roughly double the annual precipitation of eastern areas; for example, an annual average of nearly 1,500mm of precipitation has been recorded at Killarney versus 735mm at Dublin Airport (Noone *et al*. 2016). This results in the south-east of Ireland having higher exposure to drought relative to other areas. There is also seasonal variability in precipitation; for example, average monthly precipitation at Dublin Airport ranges from 49 to 56mm from February through June, and from 50 to 76mm from July through January. The spring and summer months are consequently when conditions that might potentially give rise to droughts are most likely to occur, given the coincidence of lower average monthly precipitation, milder temperatures and greater potential for high pressure systems.

Drought is a hydroclimatic hazard that is context specific, reflecting levels of surface water, ground water and/or soil moisture that are low relative to what is ordinarily expected at a given location based on past experience (Glantz and Katz 1977; Misra and Singh 2010). Conditions that are considered to constitute drought in the Irish context may therefore not in another country (or vice versa). Regardless of the locale, drought monitoring and management systems typically employ a suite of locally indicative variables to identify drought conditions, such as measures of precipitation, temperature, streamflow, soil moisture, groundwater and reservoir levels (World Meteorological Organization 2016). Although there is no universal definition, droughts are commonly described according to one of four categories (taken here from the U.S. National Drought Monitoring Center 2021):

1) *Meteorological drought:* when precipitation levels fall below some predetermined threshold over a given period of time;
2) *Vegetative* or *soil moisture drought:* when plants exhibit stress due to a shortage of available soil moisture; when there is a lack of moisture that adversely affects crops or livestock forage, it is commonly described as *agricultural drought*;
3) *Hydrological drought:* when surface and/or ground water levels drop below some predetermined threshold; and
4) *Socio-economic drought:* when adverse impacts on economic systems, livelihoods, health or social wellbeing are attributable to weather-related water shortages.

The Irish national meteorological agency (Met Éireann 2021) describes meteorological drought according to two sub-categories:

- absolute drought = a period of 15 or more consecutive days with less than 0.2mm rainfall on each
- partial drought = a period of at least 29 consecutive days with a rainfall total averaging less than 0.2mm of rain per day

Agricultural droughts as defined by Met Éireann (2021) occur when measured soil moisture deficits exceed 75mm. Hydrological droughts are identified by measuring water levels at a network of monitoring stations and comparing these to expected levels using a 'hydrological calendar' centred on 1 October, when the hydrological system is assumed to be in balance. Catchments are expected to accumulate water between 1 October and 1 April, a period when precipitation levels typically exceed evapotranspiration levels, and river flows are usually at their highest (Webster *et al*. 2017), with levels falling between 1 April and 1 October, when evapotranspiration is expected to exceed precipitation.

Until recently, systematic attempts had not been made to characterise socio-economic droughts in the Irish context. In 2022, a research team that includes several of the present authors released a searchable online database recording digitised Irish newspaper articles dating back to 1737 that contain mention of droughts and their impacts (https://doi.org/10.5281/zenodo.7216126). The frequency of newspaper reporting in a given year provides a coarse way of identifying socio-economic droughts, as is shown in Figure 1, which compares this metric with mean summer precipitation for the island of Ireland for the same year since 1950. By doing so, three things leap out from Figure 1. First, droughts with newsworthy socio-economic impacts are relatively frequent and recurrent over this period. Second, there is an anomalous interval between 1995 and the severe 2018 drought during which there are few mentions of drought in Irish newspapers, which may have created perceptions in government and the general public that drought planning need not be high priority. Third, there are instances such as in 2006 when observed precipitation levels are relatively low but newspapers contain few mentions of drought, and others such as in 1957 when newspapers contain numerous stories about drought and where the precipitation is below average but not by as much as in other periods. This reinforces the importance of recognising that meteorological values alone may not provide a precise indicator of when low water conditions present challenges for the wellbeing of residents.

The 2018 summer drought has been a catalyst for efforts to create systematic drought plans for Ireland. It emerged through a combination of low

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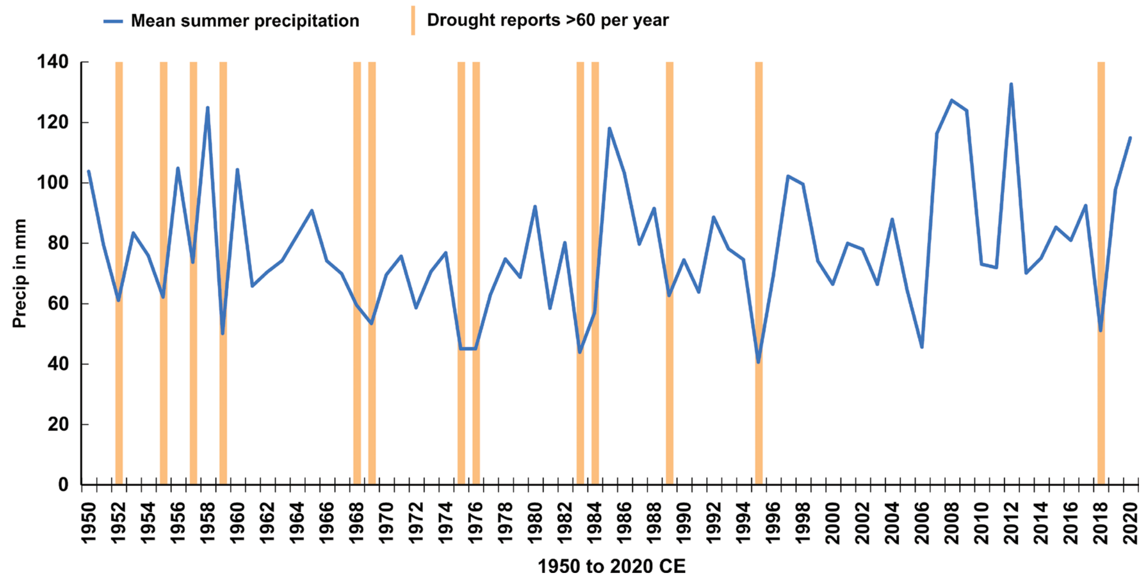

Fig. 1—Summer precipitation variability and socio-economic drought events in Ireland, 1950–2020. The dark blue line shows mean summer precipitation (June - August), derived using available stations from the Island of Ireland Precipitation Network (Noone *et al*. 2016). The orange lines indicate years with >60 published newspaper reports about drought. Although chosen here for illustrative purposes, the breakpoint of 60 corresponds with a natural break in the annual frequency of reported droughts and provide a rough indication of the relative severity of drought impacts as viewed through the lens of popular media. The figure also illustrates the disparity between meteorological records and socio-economic impacts (e.g. year 2006 or 1957), highlighting the fact that low mean precipitation values might not always translate into significant socio-economic impacts and vice versa, where under certain circumstances they might have larger impacts than might be expected.

Table 1—Agricultural impacts of 2018 drought (from Dillon *et al*. 2019)

Examples of Agricultural impacts of 2018 drought	*2018 vs 2017*
Average Irish farm income	-15 %
Cereal yields	-20 %
A decline in fodder production across most areas in turn led to higher costs of livestock feed and bedding straw; impacts on Irish beef, pig and sheep producers included:	
- gross margins for single-suckling beef producers	-19 %
- gross margins for cattle finishing operations	-11 %
- average net margins for dairy farmers	-34 %
- wholesale milk prices	-7 %
Expenditure on animal feed on dairy farms, measured by litre of milk produced	+50 % (ca)

May-July precipitation and unusually hot June temperatures (with daily highs exceeding 30ºC across much of Ireland (Met Éireann 2020)) and generated a range of impacts for rural and urban areas that are indicative of those that may be expected in future droughts. Drought conditions were visually evident first and foremost in the southeast, where grass and other vegetation turned uncharacteristically brown due to lack of soil moisture (Falzoi *et al*. 2019). In the north and west, soils tend to be heavier and hold more moisture, which delayed the emergence of moisture stress on vegetation. Significant financial losses were experienced by Irish farmers due to below-average crop and grass yields and higher costs for livestock fodder and bedding (see Table 1). County Wicklow saw a large number of wildfires, whilst tar-based road surfaces in Clare, Mayo and Offaly began to melt (O'Brien 2018). At Lough Ree, the RNLI reported significant numbers of pleasure boats running aground due to lower water levels (O'Brien 2018). Mid-summer flow levels in most rivers across Ireland were exceptionally low (Quinlan 2019) and hosepipe bans (i.e. water conservation orders) were implemented in early July, starting with Dublin County and spreading country-wide shortly thereafter; in some areas, these would not be lifted until late September. Irish Water issued repeated warnings throughout the summer about potential municipal water shortages for Dublin and other cities, a situation exacerbated by limited storage capacity, aging infrastructure, and leaky underground pipes that in some systems led to nearly half the supply being lost before reaching consumers (Murray 2018).

A number of localised water scarcity events have occurred since the 2018 drought. For example, south-central and southeast Ireland experienced low river flows and below average cereal production in 2020 following high temperatures and low precipitation in the spring of that year. Potato crops required more irrigation than usual, and newspapers remarked upon the uncertain availability of water for household and commercial use (Kellet 2020; Antwi *et al.* 2022). Hot and dry conditions in the summer of 2021 raised concerns about water supplies at some pumping stations in the counties of Limerick, Kerry, Cork, Wexford and Donegal, leading Irish Water to implement targeted night-time restrictions at some locations within counties to ensure adequate daytime water supplies (Meehan 2021). An unusually dry winter in 2021–22 had Irish Water using water tankers to supplement supplies for users in several areas across the country (Raollaigh 2022).

Whilst the 2018 drought revealed the current vulnerability of the Irish water system to drought, two other factors have helped stimulate the move to more systematic drought planning. First, demand for water is expected to grow significantly in coming decades, especially in Dublin and surrounding areas due to the combined effects of population growth and economic growth (Jacobs Engineering/Irish Water 2015). Growth in demand might be tempered somewhat should households be charged for their water consumption, but this would require revoking the current annual free allowance of 213,000 litres per year for a household of four, which would be politically contentious (O'Neill *et al.* 2018). Second, climate change is expected to have significant impacts on precipitation patterns and average temperatures in Ireland, with models suggesting the potential for increased flows in Irish catchments in winter, reduced flows in summer, and overall lower annual flows (Meresa *et al.* 2022). There is a notable degree of uncertainty in the specific levels of flows, especially in spring and autumn, with the scale of change being heavily moderated by future global greenhouse gas emissions pathways. Despite such uncertainties, given the heavy dependence of Ireland's water system on surface water, and increases in intra-annual variability and lower summer flow would, when combined with increasing water demand, amplify Ireland's future vulnerability to drought.

INSTITUTIONAL MECHANISMS FOR DROUGHT AND LOW WATER MANAGEMENT: IRELAND AND ONTARIO, CANADA COMPARED

In 2021, as part of its National Water Resources Plan, Irish Water published a twenty-three page technical appendix outlining activities to be undertaken in conjunction with other agencies (e.g. Met Éireann, Environmental Protection Agency (EPA), Office of Public Works (OPW), Electricity Supply Board (ESB), Waterways Ireland and Inland Fisheries Ireland (IFI)) to monitor for emergent droughts and communicate risks to the public, and to coordinate conservation measures for water supplies during droughts (Irish Water 2021, Appendix E). Many of the actions described in this drought plan emerged from experience during the 2018 drought crisis and have been undergoing a process of continued refinement in subsequent years.

Given the relative newness and limited testing of the Irish Water drought planning and management strategy, we carried out a systematic comparison with institutional drought management policy and planning in southwestern Ontario, Canada, a region that has rural land uses, urban settlement patterns, water demands, seasonal river flows and drought risks similar to those in southeastern Ireland; and where government agencies have longer established and better tested drought management strategies. Our aim was to generate an evidence base that facilitates ongoing refinement of Ireland's National Water Management Plan to create greater institutional resilience for drought in a changing climate. The methodological approach began by systematically identifying from published government documents in each jurisdiction the institutional responsibilities, planning priorities, monitoring systems, published drought management strategies, resourcing requirements and other relevant considerations. Using an approach familiar to researchers engaged in institutional mapping (Aligica 2006), three researchers working in concert analysed and summarised these materials in customised spreadsheets and organisational charts, structured to facilitate one-to-one comparison across common themes. Pre-existing contacts in water management positions in Irish Water and at the Ontario Ministry of Natural Resources (OMNR) and Ontario's Grand River Conservation Authority (GRCA) were consulted on multiple occasions during this process to ensure relevant publications were included. This was followed by online focus group-style workshops of approximately 2.5 hours, held on two separate occasions, that brought together project team members, two senior managers at Irish Water directly involved in drought planning, two managers at OMNR's

Surface Water Monitoring Centre who have lengthy experience in the province's low water response operations, and a water resource engineer from the GRCA who is responsible for that agency's drought response activities. These practice-led conversations organised around a set of questions circulated to participants beforehand helped the research team identify key challenges shared by the two jurisdictions and the response options available. The meetings were not recorded, allowing participants to speak freely and critically (if warranted) about their organisation's activities and the strengths and weaknesses of existing practices and policies. To accommodate this, all five members of the research team who participated in the meetings kept detailed written notes that were later consolidated and summarised in subsequent meetings for only research team members.

It should be noted that provincial governments have primary responsibility for water resource management under Canada's federal system, and so the Ontario provincial government was equated to the national government of Ireland for the purpose of this comparative exercise. A detailed organisational plan of Ontario's 'low water management' strategies, on which much of the discussion that follows is based, is included in the Supplementary Materials for this article.

DATA COLLECTION AND MONITORING RESOURCES AVAILABLE TO WATER MANAGERS IN EACH COUNTRY

A geographically expansive network for collecting meteorological and hydrometric data is an essential foundation for drought planning and response. Both Ireland and Ontario have well-established networks of hydrological monitoring stations for surface and groundwater, with a centralised agency for data collection and monitoring. In the case of Ireland, Met Éireann maintains a network of 25 staffed and automated weather stations and over 500 rainfall gauges nationwide, with data being transferred on an ongoing basis to headquarters in Dublin (Met Éireann 2022). In the case of Ontario, a network of over 600 rainfall gauges is maintained across the province, as part of a partnership between the OMNR and the federal government's environment ministry, the latter being responsible for maintaining meteorological stations across the province (Government of Ontario 2022). Hydrometric and meteorological data are monitored and analysed by the OMNR's Surface Water Monitoring Centre on an ongoing basis, which issues forecasts and warnings for both flooding and low water (i.e. drought) events (Government of Ontario 2022).

INSTITUTIONAL STRUCTURES FOR WATER MANAGEMENT

Significant differences exist between Ontario and Ireland in terms of the nature and geographical scale of government units responsible for drought policy, planning and response. In Ontario, drought policy and planning procedures are set by the provincial government as part of its wider responsibilities for managing freshwater and other natural resources. The guiding provincial *Low Water Response Plan* was first established in 2001, following an extended dry period that affected much of the province in the late 1990s, and was further revised following a severe drought in 2007 (Roth and Murray 2014). In this respect, the catalysts for formal drought/low water planning in Ontario and Ireland have been similar. Planning and implementation processes differ significantly between the two jurisdictions, however, because of differences in the nature, scale and role of lower-level institutions.

In Ireland, the delivery of water to most municipal users with piped supplies is directly overseen by a national agency established in 2014, Irish Water, with a small percentage being supplied by Group Water Schemes that source their water from public supplies (rural consumers without piped supplies typically draw their water from local wells) (Rolston and Linnane 2020). Irish Water in turn works with other relevant state-level agencies and key stakeholders such as dam operators and local governments (31 local authorities) in implementing low water responses. There is no comparable institution in Ontario, where most piped water is provided by local governments to consumers, as was the situation in Ireland prior to the formation of Irish Water. Roughly half of piped water consumed in Ontario is for residential use (Statistics Canada 2021); comparable statistics for Ireland are not readily available and this has been the subject of recent public debate (The Journal online 2023). Piped water use in Ontario is metered and, unlike in Ireland, both commercial and household users are charged at locally specified rates. As an example, at the time of publication in 2023 households in Toronto paid a rate of C\$4.3863/m^3 and commercial users C\$3.0703/m^3. Being part of the European Union (EU), Ireland's water management policies and practices, including drought planning, must conform to the EU's Water Framework Directive (WFD). In Ontario, water policy decisions must be considerate of federal government policies and regulations regarding navigable waterways and commercial fisheries, as well as joint management agreements with the United States over the Great Lakes; however, the WFD places greater constraints on water policy and planning in Ireland than do federal/international considerations for Ontario decision-makers.

LOW WATER RESPONSE PLANNING AND MANAGEMENT IN ONTARIO

For those parts of Ontario with the greatest population density there exists a type of government agency not found in Ireland, one that acts as an intermediary between provincial and local governments, known as a Conservation Authority (CA).

There are 36 CAs in Ontario, their jurisdictions corresponding with the boundaries of larger catchments in the province (except in the case of Toronto, where CA boundaries correspond more closely to the metropolitan jurisdictional boundaries). Established in the 1940s, CAs are mandated to implement catchment-scale programs to protect people and property from floods, droughts and other hazards (Conservation Ontario 2022). Under the *Low Water Response Plan*, CAs are responsible for developing and implementing water conservation measures and drought preparedness plans in conjunction with local governments; establishing standing committees for low water management with local governments, key stakeholders and user groups within their catchment boundaries; and, for communicating drought risks to key stakeholders and the wider public.

Key features of Ontario's *Low Water Response Plan* include: three defined stages of planning (pre-drought, during drought, post-drought), each with a prescribed set of actors and responsibilities; a continuous emphasis on water conservation, regardless of actual water levels in catchments in a given year; and standing committees and mechanisms for communicating water levels, conservation planning, and risks to stakeholders and the general public. Stage 1 of the planning process is described as the 'pre-drought' stage, although in practice it is carried out on a continuous basis. The key activities of Stage 1 planning occur at the catchment level, and entail the following:

- Identification of areas of potential water use conflict within a given catchment;
- Establishment of water monitoring data sources and procedures;
- Creation of a standing Water Response Team of provincial and local government agencies and key stakeholders (e.g. groups representing large water users such as farmers, aggregate mines, golf courses, bottling companies, industrial users, etc.); and
- Establishment of specific water conservation strategies and drought contingency plans.

Conservation and contingency plans include such things as increasing water storage capacity; identifying alternative sources of water for use in a drought event; and engaging large water users in water conservation and drought contingency planning.

Stage 2 of the Ontario plan refers to a period when hydrometric monitoring shows that water levels are falling in a given catchment below pre-established thresholds or 'triggers'. There are three levels of Low Water Response that may unfold during Stage 2, with thresholds that are tailored to specific catchments. For example, for the Grand River catchment—one of the largest catchments and the largest CA in southern Ontario (Figure 2)—a Level 1 Low Water Event is triggered when the following conditions are observed:

- When monthly springtime surface water flows are less than 100% of the lowest average summer month flow or, at other times of year, when monthly flows are less than 70% of lowest average summer month flow; and,
- When precipitation over the preceding 18-month period is less than 80% of average precipitation or if precipitation over the preceding three months is less than 80% of average (Shifflett 2014)

When a Level 1 event is declared, Water Response Teams are called into action, and meet with CA and OMNR officials to establish enhanced conservation measures for the catchment. These typically include actions to reduce non-essential water use, such as restricting watering of residential gardens, the washing of automobiles and encouraging residents and businesses through media outreach to engage voluntarily in reducing water use. Should any additional precipitation triggers subsequently occur, a Low Water Event Level 2 alert is issued. In the example of the Grand River catchment, these triggers are any of the following:

- 18-month precipitation falls more than 60% below average, or
- 3-month precipitation falls more than 60% below average, or
- Precipitation in any one month falls more than 60% below average, or
- Weekly precipitation in a two-week period is less than 7.6mm/week in high water demand areas (or in a three-week period for areas with moderate water demand)

In a Level 2 event, all users are asked to voluntarily reduce usage by 20%, and a range of additional restrictions are implemented to control non-essential water use by residents, with greater enforcement. The taking of water by permitted users is closely monitored by officials, and no additional permits will be issued for large water withdrawals within the affected area. The CAs review their reservoir operations and implement strategies to address supply problems as appropriate. To date, Level 2 strategies have been sufficient to meet water supply issues in Ontario during past droughts, with some local exceptions. However, should major water supply problems emerge, a Level 3 alert may be issued; in the case of the Grand River catchment, this would occur when:

- 18-month precipitation is less than 40% of average, or

Fig. 2—Location of Grand River catchment, Ontario, Canada, with main urban centres labelled. Lines within the catchment indicate local government boundaries. Map source: Redrawn by authors, using Grand River Watershed Basic Map Layers [SHP]. Waterloo, Ontario: The Department of Geography and Environmental Studies, Wilfrid Laurier University [1998].

- 3-month precipitation is less than 40% of average, or
- Precipitation in any one month is less than 40% of average

In a Level 3 situation, priority is given to municipal drinking water supplies; livestock watering and household and communal wells. Other users must reduce their consumption according to instructions from authorities or face enforcement action. Emergency water sources are brought online, and reservoir operations further modified until the Low Water Event ends.

A Low Water Event is determined to be over when precipitation indicators rise above the Level 1 warning thresholds and when monitoring of reservoir levels, surface flows, ground water levels, pond recharge rates and snowpack levels indicates the catchment has recovered. In this post-event stage (described as Stage 3 in the *Low Water Response Plan*) CAs, Water Management Teams and other actors assess the environmental, social and economic impacts of the event, identify opportunities for improving emergency water supplies for municipalities, suggest additional drought adaptation opportunities and address any gaps or deficiencies in monitoring, data analysis or other actions that were discovered during the preceding event and ensure these are addressed in future planning.

Between 2001 and 2020, slightly more than 200 catchment-level Low Water events were declared in summer months across southern Ontario, the vast majority being Level 1 events (Figure 3). The only year in which Level 3 events were declared was in 2016 in four eastern Ontario catchments. Although most of the 31 southern Ontario catchment agencies had Low Water events declared due to widespread drought conditions in 2016, these four catchments have a very different geology from other parts of southern Ontario that leaves them with limited groundwater supplies, which serve as a *de facto* contingency reserve in other catchments. Over this same period, Level 1 Low Water events were declared in the Grand River catchment in every year except 2002, 2014 and 2019, with the risk being elevated to Level 2 in six of those years. Low Water

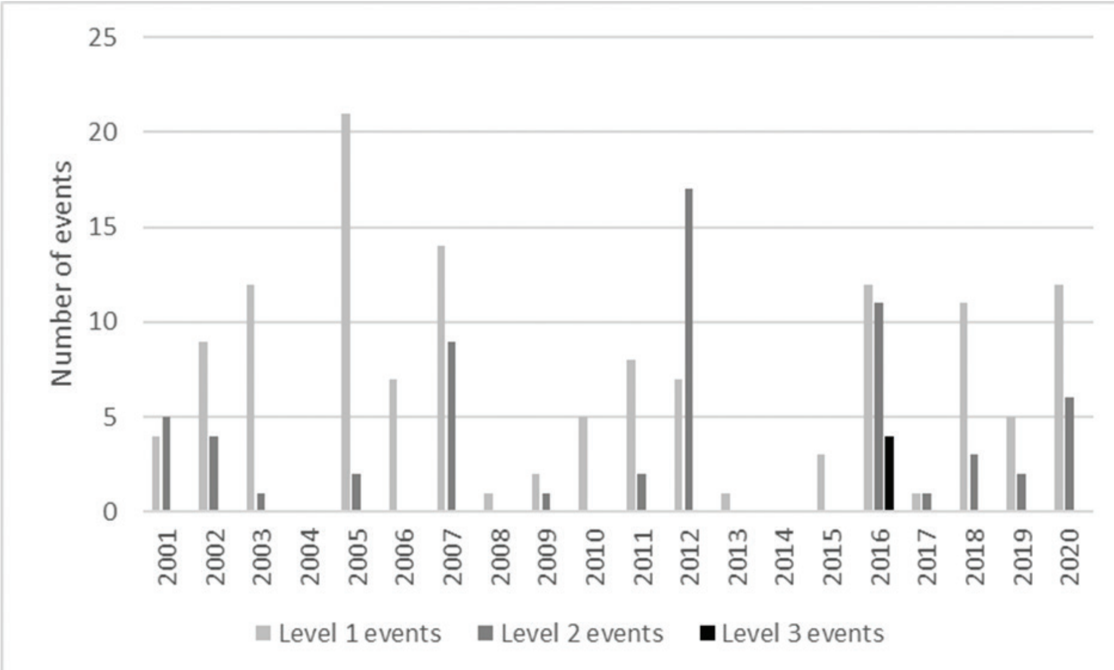

Fig. 3—Number of southern Ontario catchments declaring Low Water events in summer months, 2001–20. Data source: Ontario Surface Monitoring Centre https://www.ontario.ca/page/surface-water-monitoring-centre

events are declared more often than in many neighbouring catchments because the Grand River has a relatively large population within its boundaries—roughly 1 million people—with a limited amount of surface water to serve that population (80% of households rely on groundwater (GRCA 2023)).

Ontario's Low Water Response program has not undergone any formal performance review in the last decade, but instead relies on continuous improvement at the catchment level through ongoing collaboration between official agencies and stakeholders participating in Water Response Teams. The success of this approach was assessed in a study by Roth and de Loë (2017) who found participants to be generally satisfied with the process, particularly in terms of social and environmental outcomes, and that compliance with water conservation measures was generally satisfactory, even in the absence of systematic data collection. The study found a weakness in the system to be a hesitancy to transition from Level 2 to Level 3 events given the severe restrictions that ensue, and that large water users represented on Water Response Teams may pressure officials to go slow in this regard when conditions may demand swifter action. This was also identified as a potential weakness in an earlier study by (Disch *et al.* 2012), who noted that the impacts of climate change on catchments may force catchment authorities to create less ambiguous guidelines for the transition from Level 2 to Level 3. The GRCA has since done this, but not all catchment authorities have guidelines as specific as those described above.

DROUGHT PLANNING AND MANAGEMENT IN IRELAND

Water supply infrastructure and water management in Ireland has evolved considerably since the mid-1800s, when Dublin Corporation first began building reservoirs to supplement water taken directly from watercourses flowing through the city (Corcoran 2005; Kelly-Quinn *et al.* 2014). For most of the subsequent period, water supply infrastructure and management across the country were under the jurisdiction of local councils that focused on expanding supply for a growing and increasingly urban population. The transition to centralised management of the country's water supplies and the creation of Irish Water in 2014 emerged in response to European Union policy directives that called for national planning and charging users for water consumption. The water supply infrastructure that Irish Water inherited from local governments is heterogeneous and, in many cases, aged and in poor repair. It is estimated that 38% of the water supply is lost before it reaches consumers due to leaky distribution pipes, and Irish Water has implemented a National Leakage Reduction Programme that is expected to cost more than €1.1 billion by 2024 (Irish Water 2022).

Table 2—Data sources for identifying droughts (Irish Water 2021, Appendix E, p. 8)

Water Source type	*Indicator*	*Operators*	*Comments*
All	Rainfall	Met Éireann	Wide range of locations with daily and monthly data
All	Soil moisture deficit	Met Éireann	All Ireland, three soil categories
Rivers	Flow	Environmental Protection Agency (EPA), Office of Public Works (OPW), Electricity Supply Board (ESB)	Relatively few flow gauging stations exist, providing a long-term record that includes several significant droughts
Reservoirs	Current storage volume	ESB, IW	Data regularly available. Relatively few reservoirs providing disproportionate amount of regularly used water supply nationally
Groundwater	Groundwater level	EPA, Geological Survey of Ireland (GSI)	Number of monitoring sites and length of their records varies regionally, and historical data are limited (comprehensive network only since late 2000s).
Water Resource Zones	Demand	IW	Ongoing measurement

Irish Water's drought management planning is very much a work in progress, laying out a proposed framework for managing water supplies during drought periods and for developing a longer term, tactical planning process. While it is yet to be formally enacted, the plan outline in Irish Water's 'Appendix E' document identifies known issues with existing water supplies and identifies data sources for monitoring and the identification of drought and the bodies responsible for providing such data (Table 2). Five stages of drought have been identified, along with general measures to be undertaken at each stage (Table 3). The proposed thresholds or 'triggers' for moving between stages are based upon a combination of factors that include a meteorological drought indicator (Standardised Precipitation Index (SPI)), the return period of drought events, and operational performance considerations.

SPI is a widely used drought measure that is based on the probability of precipitation for any time scale at any location for which long term records exist (World Meteorological Organization 2012). Median average precipitation receives a value of zero on the index, with positive SPI values reflecting precipitation levels above the median, and negative values reflecting precipitation levels below the median. Near normal levels of precipitation range between +1 and -1. Values larger than +2 and lower than -2 reflect extremely wet and extremely dry conditions respectively. Moderately dry conditions are experienced when SPI values are between -1 and -1.49, and values between -1.5 and -1.99 are said to be severely dry conditions. The SPI can be calibrated for any accumulation time period between 1 and 36 months; SPI-6, for example, is an index for precipitation accumulation over a six-month period. SPI values for Ireland are derived from monthly rainfall data from a network of ten selected stations from across the country, providing data on continuous basis. The index is thus flexible and provides indicative values specific to identifying meteorological drought in an Irish context. A limitation of the SPI is that it does not account for the effects of above average temperatures that can affect evapotranspiration rates and therefore exacerbate conditions that give rise to hydrological, agricultural and/or socio-economic drought—hence the need to include other indicators, and to potentially consider using an index that includes evapotranspiration in addition to precipitation (discussed below).

Given the inherent heterogeneity of water services and the inevitable variability of drought impacts at local levels, operational metrics such as reservoir storage capacity and water demand are used in addition to SPI to establish drought level categorisations and consequent actions to be taken at each stage. The crossing of a threshold from one stage to the next does not automatically trigger responsive actions, with additional factors such as time of the year, network functionality and water user needs driving the timing and nature of responses. Irish Water's operational team is involved with all levels of drought identified in Table 3, with additional actors and agencies brought in as appropriate to assist with the coordination of responses at each stage of drought.

Table 3—Stages of drought planning (Irish Water 2021, Appendix E, pgs 13–14)

Drought stage	*Description*	*Escalation Triggers/Operational performance*
Normal	Normal monitoring	SPI exceeds -1 Water available for use (WAFU) exceeds demand, no foreseeable deficits in short/medium term
Potential drought	Management actions required to prepare for drought following extended period of dry weather	SPI of -1 or below, WAFU = demand. No impacts on customer supply, but source levels are lower than in recent drought years, supply showing stress in relation to source and storage levels. Some actions needed to improve water availability with no environmental impacts, but with proposed Inland Fisheries Ireland (IFI) interventions.
Drought	Management actions required once conditions impact customers and environment	SPI of -1.5 or below WAFU < demand. Actions taken to increase availability, reduce demand (e.g. using tankers to bring water in, nighttime restrictions, bottled water to consumers, shutting down of water treatment plants (WTP) due to low source levels). Actions to increase availability may have some low environmental impacts (consultations with environmental stakeholders, IFI interventions are in place).
Emergency (severe drought)	Management actions required as water demand exceeds availability of water for customers and environment	SPI of -2 or below Actions taken to increase availability, reduce demand (e.g. using tankers to supplement water in reservoirs for more than two days, nighttime restrictions, WTP experiencing drought conditions for more than four days or had to be shut down because of source and demand issues). Customers may experience prolonged, significant supply restrictions. Actions taken to increase raw water availability may have significant environmental impacts according to Environmental Assessment Process and through IFI consultation.
Post-drought	Monitoring and management actions focused on recovery of water supply and reviewing response to drought responses	Supply has recovered, environmental stress has eased WAFU once again exceeds demand

A range of potential drought response measures have been identified by Irish Water, drawing upon observations and experience from drought events in England in 2005, 2006 and 2012. The response measures may be applied on the demand and/or supply side (Table 4). Not all of them have been fully or widely implemented in previous droughts, and Irish Water has noted concerns regarding potential public receptiveness to some of these measures (i.e. consumer savings). For example, extensive public awareness campaigns about personal water use were run by Irish Water during the 2018 drought, and whilst these had some positive impact on household water use, research undertaken after the campaign showed that some people thought the extent and severity of the drought may have been exaggerated. However, results from a 2020 water conservation campaign indicated a more favourable response, especially among young people, suggesting that public awareness of the importance of water conservation may be changing (Irish Water 2021).

Irish Water has recognised that some of the supply-side measures listed in Table 4 may have observable environmental impacts during the construction phase and/or during water abstraction, diversion or transport. The impacts and their acceptability are judged against the degree of risk to supplies, the possible drought impacts without intervention, the

Table 4—Possible drought response measures (Irish Water, Appendix E, pgs 15–18)

Demand-side measures	*Stages of drought when implemented (see Table 3)*	*Supply-side measures*	*Stages of drought when implemented (see Table 3)*
Consumer savings from voluntary actions (e.g. information campaigns are used to raise customers' awareness and ask for water conservation measures)	All stages	Optimisation of existing sources (includes conservation of reservoir storage and maximising abstraction from rivers).	Potential drought
Large water users asked to reduce use (e.g. implement voluntary water saving efforts, use alternative supplies, conduct water audits)	All stages	Optimisation of intakes (e.g. use of submersible pumps, channelisation, temporary modification of intake structures; requires working with IFI and environmental stakeholders to consider environmental impact)	Potential drought
Additional measures to reduce system leakage and adjust water pressure within system	Potential drought, Drought, Emergency drought	Rezoning of supplies (e.g. adjusting supplies and distribution within network to reduce vulnerability at critical points)	Potential drought, Drought, Emergency drought
Imposing restrictions on consumers' water use (taking into account different categories of water use, ensuring needs of sensitive users are met, and balancing impacts on residential and business customers)	Drought, Severe drought	Recommissioning disused sources that may still be viable	Drought, Emergency drought
Interruptions to Supply (to be accompanied by mitigation measures such as water tankering, supplying bottled water, creating emergency helplines)	Drought, Severe drought	Increasing abstraction at existing sources* (this may require additional engineering or revisiting legal constraints that limit existing abstraction levels)	Drought, Emergency drought
Alternative water supplies	Drought, Severe drought	Bringing water by tanker from Water Resource Zones with adequate supplies to other, more vulnerable ones (subject to practical constraints such as road access, tanker capacity)	Drought, Emergency drought
		Construction of new satellite boreholes, where environmentally feasible*	Drought, Emergency drought
		Inter-zonal bulk transfers from areas with secure supply to those in deficit, to balance supply and demand	Potential drought, Drought, Emergency drought

* Note: there is currently no mechanism that would allow real-time introduction of these supply-side options swiftly enough to be effective once a drought has already ensued.

Table 5—Examples of environmental considerations and possible mitigation measures related to supply-side drought responses (Irish Water, 2021, Appendix E, p. 19)

Environmental sites warranting particular consideration	*Environmental considerations*	*Examples of environmental mitigation measures that may be necessary*
- Special Protection areas (European protected areas) - Special Areas of Conservation (European protected areas) - Ramsar (Internationally protected sites) - Natural Heritage Areas (NHAs) and proposed NHAs (Nationally protected sites) - Flora and Fauna protected under the Wildlife Act (National legislation for species protection) - European protected species	- Likely changes in flow/level regime and/or water quality - Catchment features sensitive to flow/level regime changes - Species that may be sensitive to changes in water levels, velocity, sedimentation, pollution, etc. - Potential perturbation to spawning areas	- Fish rescues - Fish ladder regularly checked - Increased presence to restrict poaching and protect spawning areas - Habitat restoration - Reduction of abstraction, if possible - Freshet release - Flow augmentation structures to enhance water flow/velocity - Ensure adequate post-drought monitoring for recovery

potential post-drought recovery and Irish Water's legal obligations under the Habitats Directive and Water Framework Directive. Particular concerns exist with respect to potential impacts on areas that are protected under international, European or national legislation, and on catchments containing species protected under European law or Ireland's Wildlife Act. In such cases, environmental assessments are or would need to be carried out before supply-side initiatives are implemented, with Table 5 providing examples of such considerations and possible mitigation measures.

The declaration of the end of a drought is usually based on the same criteria as its beginning, using indicators such as SPI, river flows, reservoir and groundwater levels to determine when these have returned to normal conditions for a period of time (e.g. a return to average or above average rainfall removing the soil moisture deficit, restoring river flows and groundwater levels and refilling reservoirs). Once a drought event is judged to have ended, and the drought stage is lowered to 'Post-Drought' status, the process of de-escalation of drought related response measures begins. The timing and order in which measures are stopped depends on the rate of recovery of water supplies and the social and environmental impacts of the measures in question. At this stage, the Irish drought management plan also requires that Irish Water conduct a review of how the drought was managed, with particular attention to:

- describing any environmental and other impacts that were attributable to the drought (in conjunction with the EPA and other relevant stakeholders);
- recording and reviewing all response actions that were taken and mitigation measures applied;
- identifying potential areas for improvement in the management response;
- identifying capital investments that would be useful for reducing future risks;
- assessing the performance of specific water sources during the drought relative to specific escalation points, and the amount of time necessary to recharge;
- whether the selection and definition of escalation points and the actions that followed were accurate, appropriate and timely;
- estimates of the contribution and success of demand-side measures;
- the effectiveness of communications during the drought; and
- how closely demand forecasts corresponded with actual demand patterns during the drought.

Unlike in Ontario, there is limited standing legal guidance in the RoI regarding the types of water use to prioritise during times of drought or short supply. The water supply is dependent on cooperation of other stakeholders, many of whom have control over the water source. In some cases, there are conflicting thresholds of need between water users such as fisheries, private agricultural and commercial abstractions, hydro-electricity generation, environmental uses, etc. In cases with a range of uses, public water supply abstraction has in general a lower priority than other uses (EurEau 2020). Decisions are made in the moment through national emergency management measures, with Irish Water being part of the decision-making team. There is no explicit mandate that drinking water should be the first priority during a Low Water Event; instead, there are categories of sensitive sectors such as hospitals and care homes that are recognised as requiring priority access to supplies. Coordination for priority water use under drought conditions is managed through a national emergency management structure (EurEau 2020).

The Irish Framework for Major Emergency Management was developed in 2005 and adopted by government in 2006 and sets arrangements and structures for frontline public sector emergency management in Ireland. The part of the framework most relevant to drought management is, 'A guide to severe weather emergencies'. The National Directorate for Fire and Emergency Management Crisis Management Team (NDFEM CMT) is charged with continually monitoring and reviewing information received from Met Éireann and from other sources (e.g. OPW, ESB), and decides when local authorities should be notified, or a National Emergency Coordination Group meeting should be convened. During the 2018 drought, the National Emergency Coordination Group met weekly, and directed the EPA Hydrometric and Groundwater Section, OPW Hydrometric section and IW consultants to conduct more frequent monitoring of river flows across the country (Quinlan 2019). In addition, the Drought Management Team (consisting of Irish Water units responsible for business support, environmental regulation, workflow and asset delivery, management, operations and planning) was meeting daily to assess and analyse water demand and consumption levels for every area in the country. The logistics and success of coordinating IW's drought management plans with NDFEM procedures will need to be examined and refined in future drought events.

KEY CHALLENGES IDENTIFIED BY PRACTITIONERS

Over the course of two separate online workshops held in 2021, senior managers from Irish Water, OMNR and GRCA reflected on their own experience with institutional arrangements for drought management, identified common challenges and shared ideas on best practices and opportunities for future improvements in drought management. Although this was a two-way exchange of experiences and best practices, here we focus on those topics where Ontario managers were familiar with challenges identified by their Irish counterparts and were able to share their own experiences, also reflecting upon the relative successes of different management strategies and their development.

Irish participants observed that Irish Water is a relatively new organisation, and that there are ongoing challenges related to infrastructural improvements, policy development, and resourcing the necessary modernisation of the national water supply. They emphasised that formal drought planning at a national scale had never been undertaken until the spate of recent severe droughts. A number of particular challenges and priority areas for improvement were identified. One is that there is a significant mismatch between where user demand is concentrated and locations from where water is drawn to meet that demand, creating systemic vulnerabilities to drought in certain parts of the country. For example, the average daily water abstraction from the Shannon catchment is roughly the same as the comparatively small Vartry catchment in Wicklow, despite the latter servicing a major centre of population and industry. Much of Ireland's current supply remains dependent on the legacy decisions of the earliest period of water supply development in the late nineteenth and early twentieth century, when proximity to local population centres drove early reservoir location selection, but these locations can no longer fully meet the needs of present settlement patterns and usage demands. Irish participants estimate that 60% of the existing supply network would benefit from reconfiguration, but this would require a significant capital spend increase. Legal issues with water abstraction at certain times/locations within catchments further exacerbate the vulnerability of the water system in particular regions of the country during dry periods. Many key reservoirs in Ireland are used for multiple purposes, including electricity generation, meaning that decisions about storage and release must respond to the needs of multiple stakeholders, not just Irish Water's priorities.

Ontario participants noted that large areas of the province that have high water demand have underground aquifers that can readily augment normal supplies during dry periods. Perhaps unsurprisingly, the one Ontario region to experience a severe supply shortage in recent years is located in an area with limited accessible groundwater, a situation not unlike some parts of Ireland with high water demand. The lack of large groundwater reserves in such areas emphasises the long-term need for reconfiguration of the Irish water supply network to better align it with where users are concentrated, with increased water conservation and the repair of leaky infrastructure remaining shorter-term priorities.

Another challenge in Ireland is public perception of drought risks. Irish participants felt that public awareness is slowly growing, not least because of the impacts of and media attention given to drought conditions in 2018. Achieving a widespread understanding of the need for water conservation and related compliance measures is still a work in progress, however, and it was remarked that there may be an ingrained public perception that Ireland receives such abundant rainfall that drought cannot be a serious issue. In addition, the outdated infrastructure, and leaky pipes are often perceived as the main reason for the water shortages, further complicating the situation. A June 2020 hosepipe ban in particular became a subject of contentious discussion in Irish media (Augustenborg *et al.* 2022). As a result, Irish Water managers believe that, although they have the legal authority to restrict water distribution in a drought emergency under the Water Services Act 2007, public resistance may make it difficult to actually do so.

By contrast, Ontario participants suggested that water conservation measures there have become so well established that large parts of the public accept summertime water use restrictions as being normal (a belief consistent with public opinion research conducted in a large city in the Grand River watershed (Atwood *et al.* 2007)). When Ontario water managers need to move to a Level 1 response, local governments and residents are thus able to transition efficiently to restrictions on non-essential water use, and compliance tends to be high. As in Ireland, Ontario water providers have the authority to reduce water pressure to non-complying users, but this rarely needs to be done. Ontario participants believed this high acceptance of the need for conservation (and indeed success in its implementation) is part of the reason why relatively few Low Water events have reached advanced stages in recent years. Overall, both Irish and Ontario participants agreed that continuous communications and public outreach about the need to conserve water each and every year (not just in drought years) is a key component of drought risk reduction.

Participants from both countries expressed concerns about the resilience of water supplies in a changing climate and the need for better data and modelling to support long term strategic planning. This is particularly important given that seasonality of surface water supplies in both countries makes water management challenging at the best of times, with management plans needing to account for seasonal flood risks as well as low water situations. Irish participants expressed particular concerns about extended dry periods, especially when a dry spring or summer is preceded (and its impacts compounded) by a dry winter. Given current water demand in Ireland, Irish participants predicted that a lengthy drought such as that of 1975–76 would be catastrophic if it occurred today. The comparatively brief 2018 drought led to the failure of 150 supply sources, which bodes poorly for a future where reductions in summer precipitation and increased variance in winter precipitation are projected (Met Éireann 2021).

Ontario participants noted that higher levels of government are more likely to provide financial resources for drought management in the years immediately following a severe event, but that these resources tend to decline as memory of the event recedes. Whether the very success of drought management in Ontario might give rise to a form of ‘prevention paradox’, in which increased complacency about drought hazards (with associated consequences for investment and funding) might increase the risk of future major impacts, was considered to be an open question. This, and related questions of the role of societal memory and the promotion of public and governmental recognition of drought hazards, were considered areas in which academics might usefully collaborate with water management professionals in Ireland and Ontario. Overall, given the relative newness of Irish Water and the transition to a national water management system, the need to balance the dedication of financial resources for drought management against the many competing financial needs related to modernising the country’s water supply infrastructure was regarded as an overarching challenge.

DISCUSSION AND CONCLUSIONS

Our analyses of planning documents and the online workshops that engaged practitioners from the two countries identified many useful considerations for Irish policy makers and water managers as they continue to develop management plans and strategies for drought. The general framing of Irish Water’s drought management strategy and many of its basic elements are comparable to Ontario’s *Low Water Response Plan*, creating an opportunity to incorporate many of the best practices of the latter into the Irish drought strategy as it evolves. The three-stage approach of the Ontario plan, particularly its greater specificity of pre- and post-drought event activities, and clearer designations of priority water users, is worth emulating, as is its emphasis on understanding drought risks at the catchment level. Of the many potentially useful considerations identified and outlined in this paper, the key ones may be summarised as follows:

1) There is considerable value in fostering a culture of water conservation among the Irish public to reduce pressure on water supply systems on an ongoing basis, making it easier to communicate the need for action and get widespread voluntary participation when drought conditions emerge. This is especially the case when it comes to infrequent hazards such as drought, where the public may be especially reliant on expert advice obtained through the media given their lack of personal experience (Kapuściński and Richards 2016). An examination of media reporting by

Augustenborg *et al.* (2022) found that media coverage of the 2018 drought was slow to emerge and, combined with sparse and irregular instructions given to the public on how to reduce water, likely harmed conservation efforts. The authors found that 95% of articles discussing the response of Irish Water and the Irish Government to the drought reported them as being ineffective, with communication regarding the hosepipe ban being notably poor. Irish Water has since begun to engage in conservation messaging more proactively, and it is starting to appear more regularly in the media (Raollaigh 2022). This is important, as demand-side interventions for droughts are likely to be more cost-effective and more quickly achievable than supply-side interventions, although the latter is crucial in Ireland over the longer term given the antiquated infrastructure and the lack of large groundwater reserves in some vulnerable locations to serve as fallback supplies during shortage.

2) Catchments are an effective spatial unit for making water management decisions. Decision-making at the catchment scale recognises the local specificity of both supply factors (e.g. precipitation patterns, surface water sources, groundwater sources, control structures, reservoirs, land conditions) and demand factors (e.g. absolute population, ratio of users/supply, types of users). The combination of local factors and more generic indicators such as SPI presently being developed by Irish Water would allow for closer alignment of water supply with demand and identification of areas of system vulnerability during dry periods.
3) Standing drought management teams that involve Irish Water, other relevant government agencies and representatives of key user groups should continue to be developed and could be further supported by the identification and incorporation of user groups that are not currently represented. Evidence from Ontario shows that effective drought management responses require ongoing participation from a broad cross-section of stakeholders and, as part of this process, management teams should be engaged in clarifying which users and sectors should be prioritised during Low Water events.
4) The continued assessment and refining of water discharge models, indicators being used to identify droughts, and 'triggers' for response levels, is required to ensure the data collected and monitored is best suited for the Irish context and can support planning for future challenges associated with climate change. A first step would be to assess whether aligning data collection, monitoring and modelling with catchment boundaries would provide more precise information for decision makers and, if so, to adapt response triggers accordingly.

The 2018 drought that was the catalyst for a move toward formal drought planning was not even the most pronounced drought event in modern Irish history. It is important that Irish Water's evolving drought plans be seen as the first stage of an ongoing process with ever widening engagement and collaboration with other agencies and the general public. It should not be seen to be an end point or finished product. In addition to those noted above, a number of other opportunities for further refinement of the national drought strategy were identified as part of our review. For example, the SPI is an important component in demarking the different stages in Irish drought planning (Table 3). As increased attention is given to how closely specific SPI scores correspond with the observed socio-economic impacts of droughts (e.g. O'Connor *et al.* 2022), it may be found that socio-economic impacts emerge before a particular SPI score is realised or, conversely, that a worrisome SPI score might not translate into significant socio-economic impacts under certain circumstances. There is also room to refine the time scales and deficit accumulation periods most appropriate for SPI values to be used in such a way. For example, in Ontario there are four different time scales over which low precipitation levels might trigger management actions (2 weeks, 1 month, 3 months and 18 months). It is also worth investigating whether SPEI, that includes evaporative losses in addition to precipitation deficits, might provide a more reliable drought monitor than SPI, especially given the frequent combination of drought conditions with high temperatures, and the impact of climate change on both temperature and precipitation.

Balancing environmental protection with supply needs during times of low water will be an ongoing challenge (Table 5). The drought management plan recognises that there may be locations where actions needed to respond to drought cannot be implemented without at least temporary environmental impacts, and a judgment is made by weighing the acceptability of the impact against the impacts on water supplies and the viability of alternative actions. Some of the challenging questions that will confront decision makers in such cases will include whether there are possible occasions when environmental protection interests are so great in a given location that no additional abstraction could be permitted even during a time of pronounced water supply needs? Or, should water supply needs *always* take priority in certain stages of drought?

Other difficult questions will be faced when deciding how to distribute water during future droughts designated as 'severe'. When supplies cannot meet the needs of all, the current plan calls for priorities to be based on the nature of the use, with potential exemptions, such as in 2018, when certain types of sensitive users (nursing homes, hospitals) were given priority. The implications and new challenges that might emerge from prioritising uses over users—or vice versa—could be more systematically assessed. A related question warranting further clarification is the criteria used to distinguish 'large users' (Table 4) from others, something that could become contentious, depending on the circumstances. Further clarification as to how managers will distinguish localised water scarcity events that can be managed through normal management actions from those that require triggering a formal drought declaration and formal responses would also be important. It is also worth reflecting upon the wider context within which the drought planning strategy is situated. Its success will in a significant part be determined by the reliability of water demand forecasts and the infrastructure decisions and investments that are based upon them.

As a final, general conclusion, this exercise has shown there would be considerable utility in canvassing drought management in other jurisdictions besides Ontario to identify practices that might be well suited for Ireland. Irish Water is a relatively new entity and would benefit from more peer-to-peer engagement with water managers in comparable, longer-established agencies with similar challenges. Ireland was fortunate to have gone more than two decades without a serious drought prior to 2018, but in that anomalous interlude, institutional memory and public experience of what to do when a drought hazard occurs may well have eroded. Climate change is likely to exacerbate the already numerous challenges facing Irish water managers. Important strides have been made since 2018 to address drought risks in the Irish Water Management strategy, and future refinement will benefit from better understanding the experience of other countries where drought has been a more frequent hazard. Our paper aims to further promote this as an ongoing process both by highlighting the outcomes of such discussions to date (with participants on both the Ontario and Irish sides noting the value of the exchange) and providing a foundation for future conversations.

SUPPLEMENTARY MATERIALS

Supplementary materials for this article are available online here: http://muse.jhu.edu/resolve/199

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