Contents

Introduction xi
Conversion factors xiv

1 The world's water resources and the growing demand 1
   The hydrological cycle 1
   The quantities of water in circulation 4
dew 5
   The development of water resources 6
   The dawn of public awareness 7
   population growth 7; water demand 9
Groundwater storage and development 11
   radio-active tracers for groundwater 12; underground reservoirs 13; estuary storage 14
Desalination for domestic supplies 15
   solar energy for distillation 16; atomic energy 17
Desalination for irrigation 17
   oil-fuelled processes 18; basis for comparison of costs 20
Rain-making 20
Summary of resources 21

2 Development of a watershed discipline 22
   The historical choice of discipline or disaster 22
   Organisation for mutual protection on a watershed area 23
      floods 23; soil conservation 23; economic progress 24
   Protection of streamsource areas 25
      critical areas of erosion hazard 26
   Multiple land-use planning to include recreation opportunities 29
      urban concentrations 29; public access to protected catchments 30;
      management of wildlife populations 30; management for preservation of scenery 31
   Management for maximum water output 32
      conservation v. collection 34; water loss by evaporation from reservoirs 35; community organisation by watershed boundaries 36

3 The achievement of hydrological information 38
   The first stage in research and development of water resources 38
      the variable input 38; the dividends of foresight 38; priorities in developing countries 39; routines and research 41
The sampling of rain and snow
  the catch of raingauges 41; measurements by radar 44;
  assessment of snowfall 44
Streamflow measurements
  routines and problems 45; rating by radio-isotopes 46; weirs and
  flumes 46; analytical studies of streamflow records 49
Groundwater measurements
  conventional means of exploration 50; flow and direction
  from single boreholes using radio-active isotopes 51;
  interpretation of results 52
Measurement of changes in soil-moisture storage 53
Evaporation and transpiration
  quantitative estimates 55; evaporation pans 56; evaporation from
  vegetation 58; potential evapotranspiration 63; advection 67
Recording of land-use changes 69

4 Recorded experience of the effects of forests on watersheds 72
The effects of forests on weather
  forests and mists 72; snow-trapping by forests 73;
  forests and rainfall 74
The effects of fire on watersheds 75
Beneficial use of water by forests 76
Forest plantations and streamflow in warm climates 78
Afforestation and water supplies in cool climates 81
Reafforestation of eroded watersheds 81

5 Research on forested watersheds 84
Streamflow comparisons
  clear-felling experiments 85; multiple-valley experiments with
  forest plantations 86; summary of comparisons of streamflow 87
Balancing the budgets for both water and energy
  seasonal soil-moisture storage changes 91; seasonal groundwater
  storage changes 91; leakage of watersheds 92
Measurement of incoming energy
  orientation of catchments 97
Studies of special forest components of the water balance
  interception of rainfall 98; interception and condensation of cloud,
  fog and mist 102; interception of snowfall 103; effects of forests
  on snowmelt 104; effects of streambank vegetation 105;
  control of stormflow 107; integration of results by computer 109;
  urgent needs for experimentation 113

6 Watershed experiments in tropical forests 115
An outdoor laboratory in high-altitude tropics
  a research opportunity 117; watershed experiments in East Africa
  117; can productive tree plantations safely replace
  natural forest? 118

viii
7 The effects of grazing animals on watersheds 142
   Grassland as a land use 142
   Grasslands well supplied with water 143
   Effect of grazing on marshlands 144
   Snow-trapping on cold rangelands 145
   Grazing in forested watersheds 145
   Grazing by forest wildlife 147
   Grasslands having long dry seasons 148
   Watershed experiments in range improvement 149
      a study in East Africa 149; regeneration of tropical grasslands 153;
      evidence from Australia 154; water use by improved rangeland 158
   Semi-arid grassland 159
      range management for watershed control 160; sediment flow 161;
      flood-spreading on rangelands 163; heat reflection from dry
      grassland 165
   Summary of effects of grazing on watersheds 166

8 The effects of croplands on water resources 167
   Watershed behaviour 167
      surface soil management 167
   Cropping in climates of seasonal drought 170
      soil-conservation effects in the USA 170; practical examples of
      hydrological improvements 172; experiments in the USSR 175;
      summer rainfall and winter drought 175; tropical problems 176
   Cropping in climates of water excess 180
   Semi-arid croplands 181
      a mechanism for survival 181; the penalties of misuse 182
   Protection of soil and water on arable lands 183

9 The roles of irrigation and drainage in water resources 184
   Groundwater and salinity 184
      a practical example 186
Effects on major rivers 186
  the River Volga 186; the Murray River 187
Effects of over-pumping of groundwater 190
Efficient use of water for irrigation 191
Biological hazards of irrigation 191
Water harvesting for supplementary irrigation 192
Drainage of marshlands 194
effects of swamp drainage on water quality 198; effects of swamp drainage on flood control 198; ecological effects of marsh drainage 199

10 Problems and priorities 201
In countries of advanced technology 201
  watershed effects of urban and highway development 201;
  industrial pollution 202; pollution from modern agriculture 206;
  watershed control and countryside amenity 208
In developing countries 208
  urban development and pollution 208; highway drainage 209;
  control of land use in streamsource watersheds 209; international aid 211; economic development 211; the spread of subsistence agriculture 212

Recommended reading 215
References to literature 217
Subject index 241