I. Land use and surface cover in urban ecosystems
1. Land use is the human activity associated with a land area while surface cover
   (aka land cover) is the physical material at the surface of the land.
2. Urban ecosystems have diverse land uses and covers.
   a. Urban morphological types (UMT) are the products of past and present
      land use – important meso-scale consideration.
   b. UMTs can be useful for urban planning purposes.
3. Surface cover is a finer scale version of the UMT – often built vs. green
   a. Easily surveyed via remote sensing – often a greater percentage of
      green land cover in residential peripheries.
   b. Private gardens account for ~25% of green space in the UK.
   c. Densification – one way to combat sprawl but at the expense of
      important urban green space. Socioeconomics important.

II. Urban climate
1. Luke Howard discovered the urban heat island effect in 1820!
2. Urban radiation budget is $Q^* = E_{sd} - E_{su} + E_{ld} - E_{lu}$ consisting of upward and
downward longwave and shortwave radiation.
   a. $E_{sd}$ is influenced by urban structures and shadowing.
   b. $E_{su}$ (reflection) is determined by albedo (concrete = 0.20, white paint =
      0.90, grass = 0.25, urban mean =0.15). Low albedo = higher surface
temperature.
   c. $E_{ld}$ – atmospheric counter radiation depends on water vapor.
   d. $E_{lu}$ – upward longwave radiation depends on surface temperature ($E_{lu} = \sigma \varepsilon T_o$) which depends on thermal conditions.
3. Similarly we can examine the urban heat budget $Q^* + Q_H + Q_E + Q_S + Q_F = 0$ (where
   $Q>0$ is heat toward surface (e.g. $\downarrow T_a$) and $Q<0$ (e.g. $\uparrow T_a$) is heat away).
   a. $Q_F$ is the anthropogenic heat flux (e.g. aircon) and is usually a relatively
      small contribution to the heat budget.
   b. $Q_E$ is the latent heat flux (e.g. evapotranspiration).
   c. $Q_H$ is the sensible heat flux which is the change in air temperature.
   d. $Q_S$ is the heat flux into the soil/ urban material.
4. Urban and rural sites look similar qualitatively in terms of the heat budget
   whereas night time heat flux is completely different.
   a. Radiated heat in the day is compensated equally by $Q_S, Q_H$ and $Q_E$.
   b. At night rural systems look similar (but reversed) whereas nearly all
      radiation in urban systems is compensated by $Q_S$.
5. Urban heat island (UHI) is the higher ave. temp. of urban areas relative to
   rural areas largely due to differences in night time temperatures.
   a. In urban areas, “the source of energy for this compensation [$Q_S$] is the
      heat stored during daytime in the urban construction material, which acts
      like a battery, charged during daytime and discharged during night-time”.
   b. UHI thus depends on construction materials, structure, aircon etc.
   c. UHI is strongest in the summer and during early evening hours.
   d. Because $Q_S$ nearly fully compensates for negative $Q^*$ during night, $Q_H$
      remains <0 and air temp. does not drop like it does in rural areas.
e. Urban canyons are also important components of urban climate and can heat quickly with high aspect ratios, low sky view etc. With less sky to radiate to air temperature is slower to cool off with low sky view.

6. Precipitation tends to also increase (often with specific diurnal patterns) in urban areas through disruption of circulation and an increase in aerosols and therefore nucleation potential.

7. Climate change, heat waves and (briefly) human health.
   a. Global warming will cause cities to warm in addition to UHI and in some cases the contribution to \( \Delta T \) will be comparable.
   b. Hong Kong: 3-6\(^\circ\)C \( \Delta T \) w/ warming and 3.7-6.8\(^\circ\)C \( \Delta T \) w/ warming, UHI.
   c. Heat waves under climate change will be more intense, more frequent and have a longer duration.
   d. High mortality related to UHI in Hong Kong. What about global warming and UHI?

III. Urban hydrology

1. The water cycle consists of evaporation (e.g. from the ocean), condensation, storage in the atmosphere and then precipitation (often on land). Rainfall then goes back to the ocean via runoff, streams, and groundwater flow.

2. Precipitation is the key input of water into urban ecosystems.
   a. Characterized by rain depth, intensity and duration. Durations of less than 12hrs are key for urban design as short durations correspond with high intensity rainfalls.
   b. Intensity determines outcome of infiltration vs. evapotranspiration vs. runoff.
   c. Imported water (e.g. for drinking) is also an important input especially for the long-term. Similarly, wastewater is a key output.

3. Evapotranspiration (ET) is the transformation of water (from trees, water bodies, plants, soils) from the liquid phase into vapour.
   a. ET can make up to 70% of “loss” of precip (in the long term).
   b. Evaporative cooling can result from ET.
   c. ET is lower in cities because fewer plants and less water available for evaporation -> contributes to UHI.

4. Infiltration is decreased in urban areas w/ impervious materials (e.g. rooftops, asphalt). In nature, most precip goes through infiltration.
   a. Water retention capacity of a soil is determined by volumetric water content and capillary suction (sands vs. clay vs. gravel).
   b. Clay has high capillary suction, therefore at equal water content clay seems dry relative to sand and won’t drain as fast.
   c. Hydrology of semi-permeable surfaces (e.g. porous asphalt, green roofs) are more complex – somewhere “in between”.
   d. Different types of pavement have varying permeability values. Often depends on age (old pavements clog), structure, slope...

5. Interception (e.g. rain falling on leaves) usually lower in urban areas is an “initial loss” (vs. infiltration, a continuous loss).

6. Depression storage (rain accumulating in small basins or puddles) leads to water evaporating or slowly infiltrating.

7. Surface runoff occurs when rain intensity exceeds infiltration capacity and water flows overland.
a. Surface runoff volume is equal to precip – losses (interception, depression storage, infiltration, ET [minor “event-based” loss]).
b. Runoff coefficient is the ratio of runoff to rainfall (from 0-1).  
c. In urban systems there is usually a diminished “lag time” between time of rainfall and time of discharge in addition to high flows/ runoff after rainfall.  
d. Runoff also contributes significantly to pollution and erosion.  
e. A significant component of urban sustainable initiatives is therefore to reduce impervious surface cover.

IV. Urban soils

1. Urban soils are characterized as all other soils BUT also are characterized as having natural and anthropogenic inputs, subject to often intense human impacts (e.g. sealing).
   a. Alternatively, urban soils form through climate, organisms, time, topography and parent material which are then altered anthropogenically via disturbance, altered resources and heterogeneity leading to novel and modified soils.
   b. In urban areas soils are primarily seen as having infrastructural use.
   c. Soil sealing (thin layer limiting infiltration) can result from compaction, paving, artificial covers (plastic, metal, etc.).
   d. Unsealed soils are “substance sinks” (can act as carriers for contaminants) and structure is highly dictated by mechanical impacts.

2. Common human impacts on urban soils include sealing, paving, building over, raising (e.g. urban parks), excavation, compaction, desiccation, contamination.

3. Pollution is often high in urban soils from atmospheric deposition, traffic related emissions, hazardous spills, industrial deposits, replacement soil, and urban runoff/ water pathways.

4. Belowground UHI impacts can occur in soils covered by gravel/ pavement.

5. Biodiversity within soils can vary significantly based on material, landscape, temperature and land use.

6. Soil often underappreciated, e.g. compared to air and water. But still a precious and non-renewable resource. Soil conservation and soil considerations in planning are becoming important features of urban design.

V. Urban ecosystem summation (from Kaye et al. 2006)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Urban core</th>
<th>Residential</th>
<th>Forest</th>
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</thead>
<tbody>
<tr>
<td>Human resource inputs</td>
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<td>low</td>
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<tr>
<td>Water drainage</td>
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<td>mostly engineered</td>
<td>natural flows</td>
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<tr>
<td>Plant/ soil cover</td>
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<td>intermediate</td>
<td>high</td>
</tr>
<tr>
<td>Infiltration</td>
<td>low</td>
<td>intermediate</td>
<td>high</td>
</tr>
</tbody>
</table>