4) Natural Resources

- **a) USDA Soil Survey of Hualapai and Havasupai Area - extract**
- **b) Hualapai Soil and Water Conservation District**
- **c) International Panel on Climate Change excerpts**
- **d) Low Impact Development**

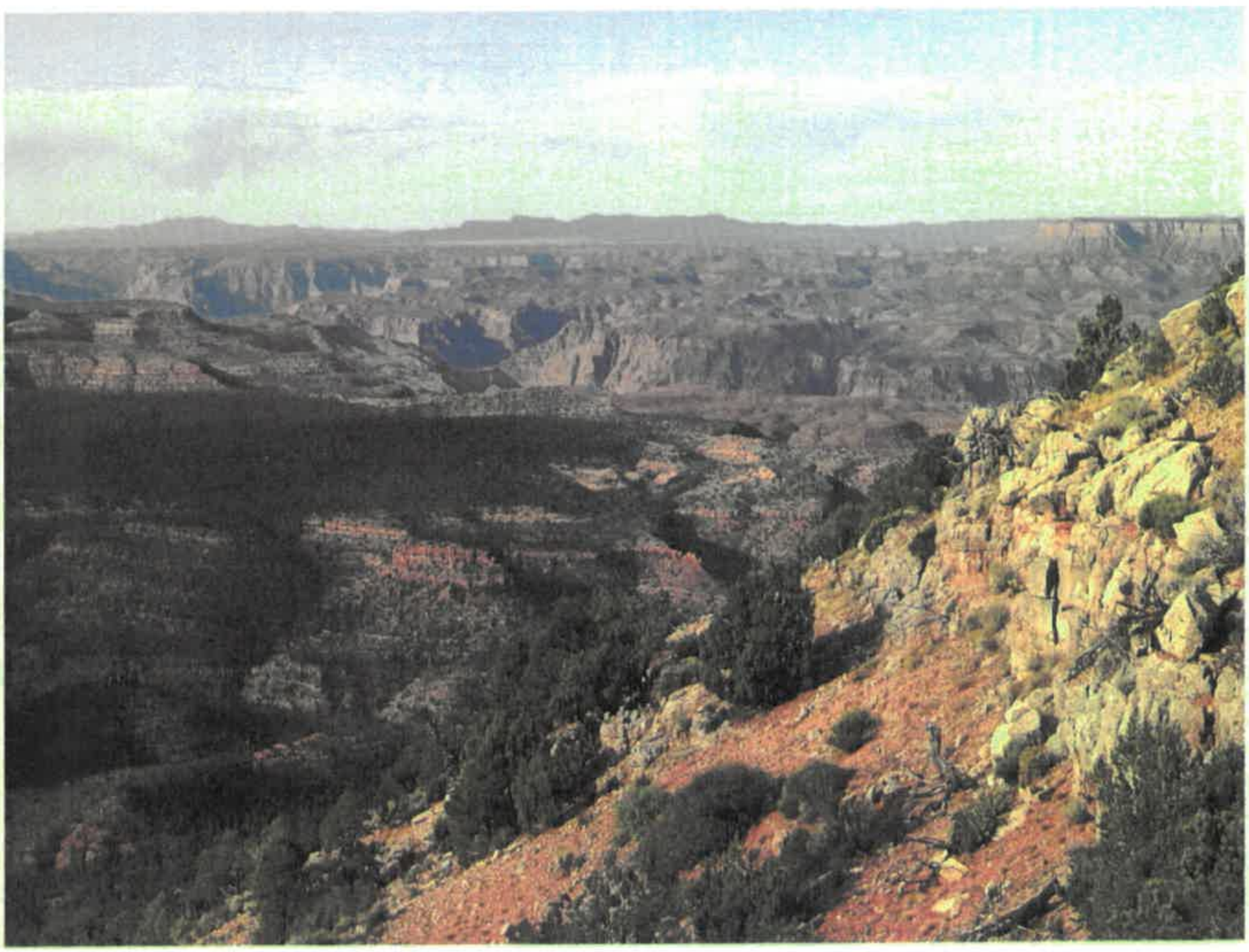
USDA United States Department of Agriculture

Natural Resources Conservation Service

In cooperation with United States Department of the Interior, Bureau of Indian Affairs; the Arizona Agricultural Experiment Station; and the Hualapai and Havasupai Tribes

Soil Survey of Hualapai-Havasupai Area, Arizona,

Parts of Coconino, Mohave, and Yavapai Counties



Foreword

This soil survey contains information that can be used in land-planning programs in the survey area. It contains predictions of soil behavior for selected land uses. The survey also highlights limitations and hazards inherent in the soil, improvements needed to overcome the limitations, and the impact of selected land uses on the environment.

This soil survey is designed for many different users. Farmers, ranchers, foresters, and agronomists can use it to evaluate the potential of the soil and the management needed for maximum food and fiber production. Planners, community officials, engineers, developers, builders, and home buyers can use the survey to plan land use, select sites for construction, and identify special practices needed to ensure proper performance. Conservationists, teachers, students, and specialists in recreation, wildlife management, waste disposal, and pollution control can use the survey to help them understand, protect, and enhance the environment.

Great differences in soil properties can occur within short distances. Some soils are seasonally wet or subject to flooding. Some are shallow to bedrock. Some are too unstable to be used as a foundation for buildings or roads. Clayey or wet soils are poorly suited to use as septic tank absorption fields. A high water table makes a soil poorly suited to basements or underground installations.

These and many other soil properties that affect land use are described in this soil survey. Broad areas of soils are shown on the general soil map. The location of each soil is shown on the detailed soil maps. Each soil in the survey area is described. Information on specific uses is given for each soil. Help in using this publication and additional information are available at the local office of the Natural Resources Conservation Service or the Cooperative Extension Service.

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Soil Survey of Hualapai-Havasupai Area, Arizona,
Parts of Coconino, Mohave, and Yavapai Counties

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United States Department of Agriculture, Natural Resources Conservation Service,
in cooperation with
the Arizona Agricultural Experiment Station; the United States Department of the Interior, Bureau of Indian Affairs; and the Hualapai and Havasupai Tribes

General Nature of the Survey Area

Physiography

The Hualapai-Havasupai soil survey area covers 1,180,540 acres in northwestern Arizona (fig. 1). It consists of two Indian reservations administered by the United States Department of the Interior, Bureau of Indian Affairs (BIA). The Hualapai Indian Reservation is 992,463 acres in size. It is mostly in Coconino and Mohave Counties, but a small area near the southeastern boundary is in Yavapai County (fig. 2). The Havasupai Indian Reservation is 188,077 acres in size. It is entirely in Coconino County. The Hualapai Reservation is a broad, irregular U-shaped area that follows the course of the Colorado River channel. Each wing of the "U" extends nearly 50 miles. The overall width is approximately 60 miles. The Havasupai Reservation branches off the eastern wing and adjoins the Grand Canyon National Park to the northeast.

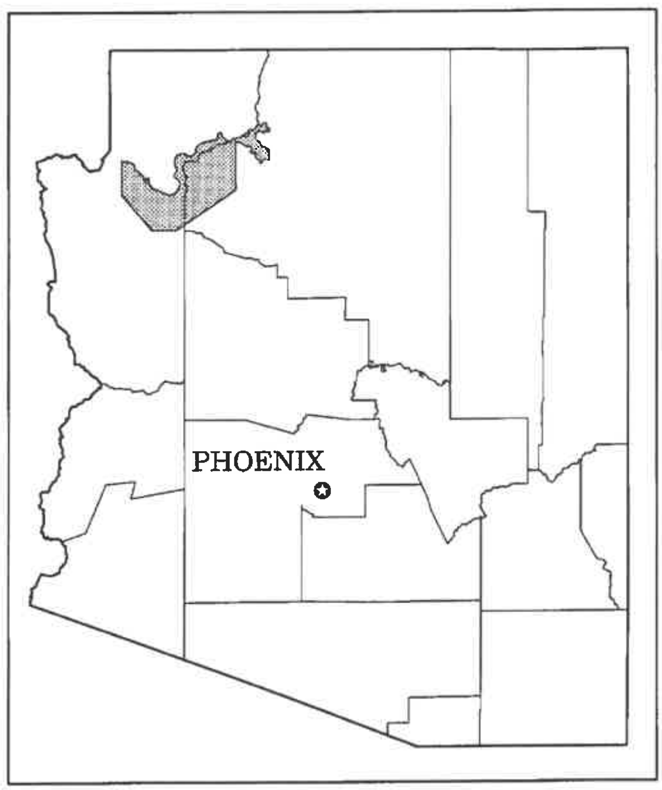


Figure 1.—Location of the Hualapai-Havasupai area in Arizona.

The Hualapai and Havasupai Indian Reservations are in the southwestern section of the Colorado Plateau. This area is subdivided into two irregular plateaus, the Hualapai Plateau and the western part of the Coconino Plateau (fig. 3). The Hualapai Plateau has an average elevation of 5,000 feet. It is bounded on the west by the Grand Wash Cliffs, which separate the Colorado Plateau from the Basin and Range province (Twenter, 1962). The Hurricane Fault in Peach Springs Canyon separates the eastern margin of the Hualapai Plateau from the Coconino Plateau. The Coconino Plateau has an average elevation of 6,500 feet.

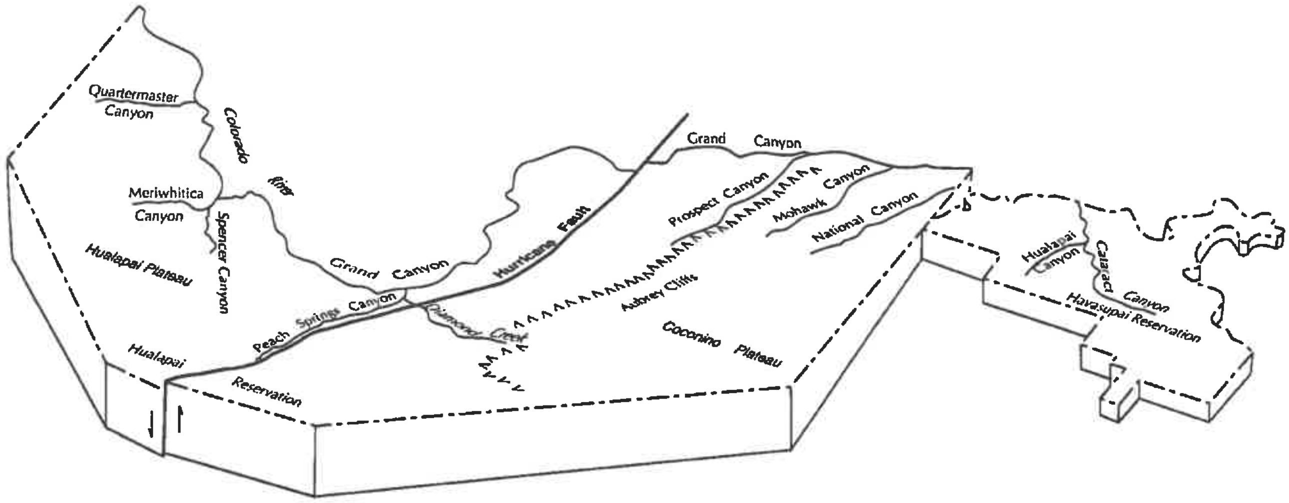


Figure 2.—Planar view of the Hualapai-Havasupai area.

The plateaus are broken to the north by steep, rugged canyons that merge with the Grand Canyon and the deeply entrenched Colorado River. Ephemeral drainages that flow to the northeast are in Quartermaster, Meriwhitica, Peach Springs, Prospect, Mohawk, and National Canyons. Spencer, Diamond, and Havasu Creeks drain to the northwest and have a perennial flow from springs. Havasu Creek flows through Cataract Canyon below its confluence with Hualapai Canyon.

The southern upland areas in the survey area are situated on the gently undulating terrain of the Hualapai and Coconino Plateaus. They are underlain by nearly horizontal Paleozoic sedimentary rocks with an average regional dip of 1 degree northeast.

The highest elevation in the survey area is about 7,392 feet at Manzanita. Manzanita is about 7 miles west of Thorton Lookout, near the western edge of the Coconino Plateau on the Aubrey Cliffs. The lowest elevation in the survey area is 1,157 feet at the Colorado River near Lake Mead.

History and Development

The Hualapai and Havasupai Indians are members of the Yuman-speaking tribes, collectively known as "Pai." Their aboriginal lands covered over 5 million acres of diverse topography in northwestern Arizona. The area, inhabited since the 12th century, was utilized by 13 hunting and gathering bands, whose subsistence lifestyle centered on seasonal movement to locations with abundant plant and animal resources (McGuire, 1987). Agriculture was common along the perennial streams and near springs in canyon walls.

The first direct contact with Anglos occurred in 1776, during the expedition of Franciscan missionary Francisco Garces. Another 70 years passed before exploration and survey parties from the United States reached the area after the territory was transferred from Mexico to the United States (McGuire, 1987). The geographic distribution of the Pai bands led to the misconception of the people as two different tribes—the "Hwala'pay," or Pine Tree People, and the "Havasuw`apa," or Blue Green Water People.

The killing of a Hualapai leader by Anglos in 1866 led to the Hualapai War of 1866-1869 (Dobyns and Euler, 1960). The defeated Hualapais were marched to the Colorado Indian Reservation for internment. The eastern bands of the Havasupais escaped the encampment due to their isolation in the steep canyon and continued their aboriginal hunting and gathering lifestyle.

In 1883, the Hualapai Indian Reservation was established for the survivors of the western Hualapai bands. The reservation encompassed approximately 900,000 acres of the Hualapais' original land. Anglo colonization and heavy cattle grazing during the brief absence of the Hualapais prevented a return to native subsistence activities. Employment was sought in nearby railroad towns or with ranchers and miners. During the Depression, many of the Hualapais returned to the reservation to work with the Civilian Conservation Corps and remained to raise cattle after the program ended. In 1960, half of the 702 Hualapais on the tribal rolls lived permanently in Peach Springs (McGuire, 1987).

In 1882, only 518 acres were set aside to establish the Havasupai Reservation near Supai Village in Havasu Canyon (Dobyns and Euler, 1960). During the 1880's, mining exploration in Cataract Canyon and the development of Grand Canyon tourism greatly diminished the Havasupai subsistence lifestyle. Wage labor was sought outside the village, and many Havasupais were employed at Grand Canyon Village. In 1939, Tribal governments were established under the Indian Reorganization Act (Marshal, 1971). The Havasupai Reservation was expanded in 1975 to more than 188,000 acres, returning part of the traditional lands on the Colorado Plateau to the tribe. An additional 95,300 acres of the Grand Canyon National Park are presently reserved as traditional "Havasupai Use Lands."

The Hualapai population currently totals 2,200. Nearly half of this total is under the age of 16. Tribal enterprises include cattle ranching, wildlife hunting permits, commercial timber harvest, and Colorado River raft operations. Education is another important source of employment. However, only 28 percent of the potential labor force is employed locally on the reservation (Watahomigie, 1988).

The only current settlement on the Hualapai Reservation is the town of Peach Springs. It is located on old Highway 66 along the Santa Fe Railroad about 120 miles west of Flagstaff and 50 miles east of Kingman. Peach Springs has a grade school, a post office, a general store, two gas stations, a tribal office complex, and a U.S. Indian Health Service clinic (Watahomigie, 1988).

Currently, the population of the Havasupai Tribe is about 500. The main tribal enterprise is tourism. The tribe operates a tourist office, a lodge, campgrounds, a cafe, and a grocery store. The reservation has over 20,000 visitors each year and is famous for its turquoise-colored perennial stream and waterfalls below the village. Major sources of employment are tourism, education, clerical work, and construction. The unemployment rate in 1987 was 38 percent (Ariz. Dept. of Commerce, 1988).

The only current settlement on the Havasupai Reservation is the village of Supai in Havasu Canyon. It is accessible only by foot, horse, or helicopter. The trail from Hualapai Hilltop (Panya Point) to Supai is 8 miles long. The trailhead is reached by BIA Route 18, which branches north from Highway 66 east of Peach Springs. Supplies and building materials must be packed by horse, mule train, or chartered helicopter. The U.S. Postal Service transports mail to and from the village by packhorse train. Supai has an elementary school, post office, tribal office and community building, and Indian Health Service clinic.

Natural Resources

Natural resources in the survey area include soil, water, wildlife, minerals and geologic materials, timber products, grazeable woodland, and rangeland. Conservation and utilization of these related resources are tied to soil properties that affect use and management.

Mineral resources include uranium, vanadium, and copper and small areas of gypsum (McKee, 1977). Uranium is found in solution collapsed breccia pipes within the Redwall Limestone in the northeastern part of the survey area. Copper bearing minerals are also associated with the breccia pipes (Billingsley). Copper was once mined at the Ridenour mine west of Prospect Valley.

Local deposits of Tertiary and Quaternary age gravel provide a source of sand and gravel for road material. Other geologic materials include limestone, sandstone, and travertine (McKee, 1977). Limestone is quarried from the Redwall Formation in the southeastern corner of the survey area. Flagstone is quarried from small sandstone deposits near the southwest boundary of the Hualapai Reservation.

Water is a limited resource within the Hualapai and Havasupai Reservations. Sources of surface water are the Colorado River, water entrenched in the Grand Canyon,

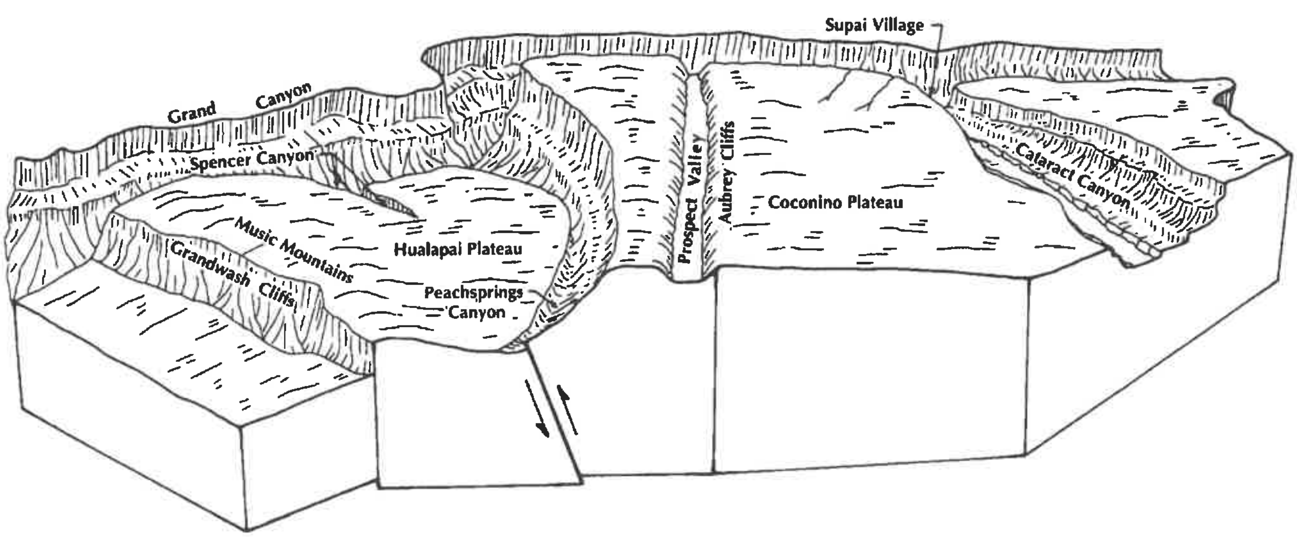


Figure 3.—Cross-sectional view of the physiography of the survey area.

and springs located in deep tributary canyons. Significant flows originate from Warm, Diamond, Spencer, Meriwhitica, and Quartermaster Springs on the Hualapai Reservation and Havasu, Topocoba, Bachathaiva, and High Wall Springs on the Havasupai Reservation. The inaccessible locations of several of these springs limit use for water development. Potential groundwater supplies are limited to aquifers in the Muav Limestone, Coconino Sandstone, and Tertiary alluvial deposits (Twenter, 1962). Nearly all of the developed water is used for livestock. It is either supplied to troughs and drinkers by networks of pipeline from wells and water catchments, or it is impounded in earthen stock tanks. Domestic water in Peach Springs is piped from a well near Truxton. Havasu Creek flows through Supai Village, providing a perennial water source for irrigation and domestic use.

The major land uses of the survey area are livestock grazing and timber production. Secondary uses are wildlife habitat and recreation. Small areas of cropland are utilized near Supai Village, where water is abundant for irrigation.

Climate

Table 1 gives data on temperature and precipitation for the survey area as recorded at Supai in the period 1957 to 1987 and at Seligman (outside the survey area) in the period 1905 to 1993. Table 2 shows probable dates of the first freeze in fall and the last freeze in spring. Table 3 provides data on length of the growing season.

In winter the average temperature at Supai is 48 degrees F and the average daily minimum temperature is 33 degrees. The lowest temperature on record is -4 degrees in January, 1979. In summer, the average temperature is 79 degrees and the average daily maximum temperature is 96 degrees. The highest recorded temperature is 112 degrees in June, 1981.

In winter the average temperature at Seligman is 39 degrees F and the average daily minimum temperature is 23 degrees. The lowest temperature on record, which occurred at Seligman is -17 degrees F in December, 1931. In summer, the average temperature is 67 degrees and the average daily maximum temperature is 86 degrees. The highest recorded temperature at Seligman is 104 degrees in July, 1932.

The total annual precipitation at Supai is 8.5 inches. Of this, 4.3 inches, or 50 percent, usually falls in April through September. The growing season for most crops falls within this period. In 2 years out of 10, the rainfall in April through September is less than 1.5 inches. Thunderstorms occur mostly from July through September.

The total annual precipitation at Seligman is 11 inches. Of this, 6 inches, or 55 percent, usually falls in April through September. The growing season for most crops falls within this period. In 2 years out of 10, the rainfall in April through September is less than 2 inches. Thunderstorms occur mostly July through September.

Growing degree days are shown in table 1. They are equivalent to "heat units." During the month, growing degree days accumulate by the amount that the average temperature each day exceeds a base temperature (40 degrees F). The normal monthly accumulation is used to schedule single or successive plantings of a crop between the last freeze in spring and the first freeze in fall.

Major Land Resource Units

Major land resource areas (MLRAs) are geographically associated units that have a particular pattern of soils, climate, water resources, and land use (USDA, Handb. 296, 1981). Identification of MLRAs is important in statewide agricultural planning and has value in interstate, regional, and national planning. The MLRAs consist of at least several thousand acres, although much smaller areas of a characteristic MLRA may occur in a localized area. The MLRAs have broad ranges of elevation, precipitation, location of occurrence, and other characteristics. At the state and local level, MLRAs are usually subdivided into Major Land Resource Units (MLRUs) for more detailed inventory and planning purposes. The MLRUs that occur within the Hualapai-Havasupai soil survey area have a more narrow range of characteristics, such as elevation, precipitation, and temperature, than is characteristic for an MLRA on a regional basis. The general soil map at the back of this soil survey shows the distribution of MLRUs in the survey area.

The Hualapai-Havasupai soil survey area consists of five MLRUs (fig. 4). From the bottom of the Grand Canyon to an elevation of about 4,500 feet is the Grand Canyon Desert Shrub (MLRU 30-2AZ). The Colorado Plateau Mixed Grass Plains (MLRU 35-1AZ) and the Grand Canyon Woodland-Shrub (MLRU 39-3AZ) are at elevations ranging from about 4,500 to 6,600 feet and are the most widespread of the MLRUs in the survey area. The Colorado Plateau Sagebrush-Grassland (MLRU 35-3AZ) occupies an area dominantly within the Havasupai Reservation. The Mogollon Plateau Coniferous Forest (MLRU 39-1AZ) occurs only in the highest parts of the survey area near the Aubrey Cliffs and near Thorton Lookout. These MLRUs are described in the following paragraphs.

MLRU 30-2AZ—Grand Canyon Desert Shrub. The Grand Canyon Desert Shrub resource unit is primarily in canyons and on dissected plateaus in the survey area (fig. 5). Elevations are dominantly 2,000 to 5,000 feet. The most prominent feature in the unit is the Grand Canyon.

The climate is arid and warm. Annual precipitation ranges from about 8 to 12 inches at the higher elevations.

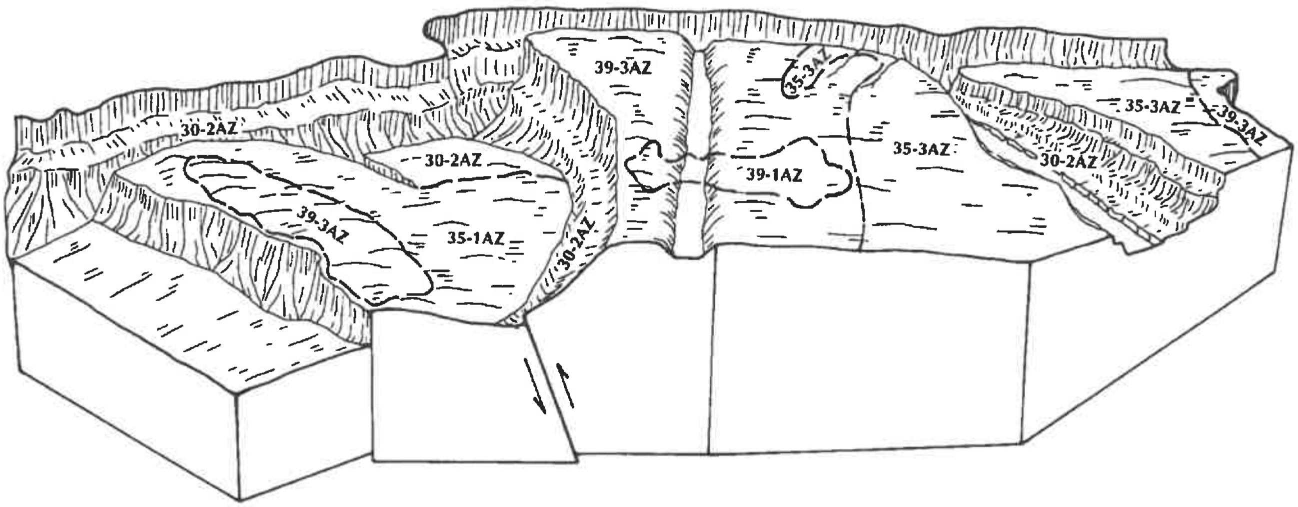


Figure 4.—Generalized diagram of the major land resource units in the survey area.

The average air temperature ranges from 57 to 68 degrees F. The average frost-free period ranges from 130 to 220 days.

The plant communities in the upland areas are dominated by blackbrush but also include minor amounts of creosotebush, ratany, yucca, white bursage, winterfat, and various cactus species. Dominant grasses on upland soils include big galleta, bush muhly, Indian ricegrass, desert needlegrass, dropseeds, and perennial threeawns. Bottomland soils are dominated by big galleta, bush muhly, Indian ricegrass, perennial threeawns, dropseeds, Mexican bladdersage, white burrobrush, and buckhorn cholla. Wet periods, particularly during the spring months, produce large quantities of annual vegetation that are important to wildlife. The vegetation consists of annual grasses and forbs such as lupine, desert Indianwheat, primrose, sixweeks grama, and sixweeks fescue.

This unit is used dominantly for recreational purposes. On the reservations, camping, hiking, hunting, fishing, and boating are popular. This area is also used for rangeland and wildlife habitat and for limited livestock grazing. Major management concerns include inadequate livestock watering facilities, the abundance of shrubby species, and steep slopes.

This MLRU makes up about 29 percent of the survey area and is subdivided into 2 map units on the general soil map. Soils that occur in this MLRU in the survey area include highly variable Torriorthents; very shallow and shallow Splanod and Hindu soils; and very deep Arizo, Lostman, Naha, Nickel family, and Cowan family soils. Rock outcrop is also a major component.

MLRU 35-1AZ—Colorado Plateau Mixed Grass Plains. This MLRU is mainly undulating to hilly plains with an occasional deeply incised, steep-sided drainageway (fig. 6). Elevations range from about 4,000 to 7,200 feet. No perennial streams are in the area. Ground water is usually deep and often of poor quality.

Precipitation ranges from 10 to 18 inches per year. Fifty percent of it occurs from October to May as snow or rain. The snow occurs during December, January, and February. The mean annual air temperature ranges from 50 to 55 degrees F. The frost-free period ranges from 130 to 180 days.

The upland soils are dominated by needlegrasses, Indian ricegrass, galleta, and blue grama. Important shrubs are fourwing saltbush, blackbrush, winterfat, and Bigelow sagebrush. Some scattered open savannahs exist on shallow soils and are dominated by Utah juniper and Stansbury cliffrose.

This unit is primarily used for livestock grazing. In some areas overgrazing has resulted in the deterioration of range quality and in wind and water erosion. Gully erosion is a problem in some of the drainageways.

This MLRU makes up approximately 26 percent of the survey area. It is subdivided into 4 map units on the general soil map. Many of the soils in this area, such as Curhollow, Winona, and Meriwhitica soils, are shallow to limestone bedrock. The Rolie soils are very shallow and shallow to a calcium carbonate cemented hardpan. The Peachsprings and Poley soils are very deep and occur on fan terraces.

MLRU 35-3A—Colorado Plateau Sagebrush-Grassland. This unit is characterized by rolling hills and plateaus. Elevations range from 4,600 to 6,100 feet. Precipitation ranges from 10 to 12 inches per year. Sixty percent of the precipitation falls as snow or rain during the

Figure 5.—An area of Arizo soils in Peach Springs Canyon in MLRU 30-2AZ. The canyon escarpments are rock outcrop and shallow to very deep Torriorthents.

winter months. The remainder falls as rain from June through September. May and June are typically dry. The average annual air temperature ranges from 52 to 56 degrees F. Winters are cold, and summers are warm. The frost-free period ranges from 135 to 175 days.

Indian ricegrass, needleandthread, and western wheatgrass are the dominant cool season grasses in this unit. Galleta, black grama, blue grama, and sand dropseed are the major warm season grasses. Winterfat, fourwing saltbush, and Wyoming big sagebrush are the most important shrubs.

This MLRU is used dominantly for livestock grazing. The unpredictable rainfall creates management concerns for livestock operators. Pastures frequently do not receive enough rainfall to produce the normal amount of feed. Stock tanks are often dry. Water catchments are being used to harvest rainfall. Wells are very deep and widely scattered. Springs are also scarce. Irrigated water has not been developed, and no perennial streams exist in the unit.

Overgrazing is a management concern that results in increased densities of sagebrush. Serious gully erosion occurs in some areas. The shallow soils and the high content of rock fragments make reseeding difficult. The shallow depth to bedrock increases the hazard of erosion.

This MLRU makes up only 9 percent of the survey area. Most of the soils in this unit are very shallow and shallow to limestone bedrock. The most common soils are Winona, Curhollow, and Puertecito soils.

MLRU 39-3AZ—Grand Canyon Woodland-Shrub. Elevations range from 4,500 to 6,600 feet. Undulating plateaus and small mesas are the characteristic topography. The mean annual precipitation ranges from about 14 to 18 inches. Sixty-five percent of the precipitation occurs from October through May. Snow occurs from November through mid-April. The remainder of the precipitation falls as rain during June through September, often during thunderstorms. The mean annual temperature ranges from 49 to 55 degrees F. The average frost-free period ranges from 120 to 175 days.

Approximately 80 percent of this unit has a cover of Utah juniper and Colorado pinyon or singleleaf pinyon. Important understory plants include turbinella oak, desert ceanothus, Stansbury cliffrose, Wyoming big sagebrush, mountain big sagebrush, true mountain mahogany, and fourwing saltbush. The major grasses include muttongrass, bottlebrush squirreltail, blue grama, and sideoats grama. Banana yucca, running pricklypear, and Fremont barberry are present in minor amounts.

This MLRU provides firewood, posts, wildlife habitat for big game species, and pinyon nuts. The understory plants provide some grazing for livestock. About 20 percent of the unit is shrub-grassland that has usable forage for grazing. Water is scarce throughout the area. Stock tanks often fill with snow melt but may go dry if summer rains do not refill them. This unit has no perennial streams, and springs are scarce. Wells are deep and widely scattered.

This MLRU makes up approximately 32 percent of the survey area. It is subdivided into 4 map units on the general soil map. The majority of the soils and map units in the survey area are in this MLRU. The soils range from very shallow to very deep and have a variety of parent materials.

MLRU 39-1AZ—Mogollon Plateau Coniferous Forest. This MLRU consists of undulating to mountainous topography that has scattered areas of steep, low hills. Elevation in this survey area ranges from about 6,200 to 7,900 feet. The mean annual precipitation ranges from about 18 to more than 20 inches. Approximately 65 percent of the precipitation falls as snow. Snow cover may remain on the ground from November through April. The mean annual temperature ranges from 45 to 54 degrees F. The frost-free period ranges from 120 to 150 days.

The dominant vegetation in this MLRU is ponderosa pine (fig. 7). Another important tree species is Gambel oak. Important understory grasses and shrubs include Arizona fescue, sheep fescue, mountain muhly, prairie junegrass, muttongrass, pine dropseed, dryland sedges, Wyoming big

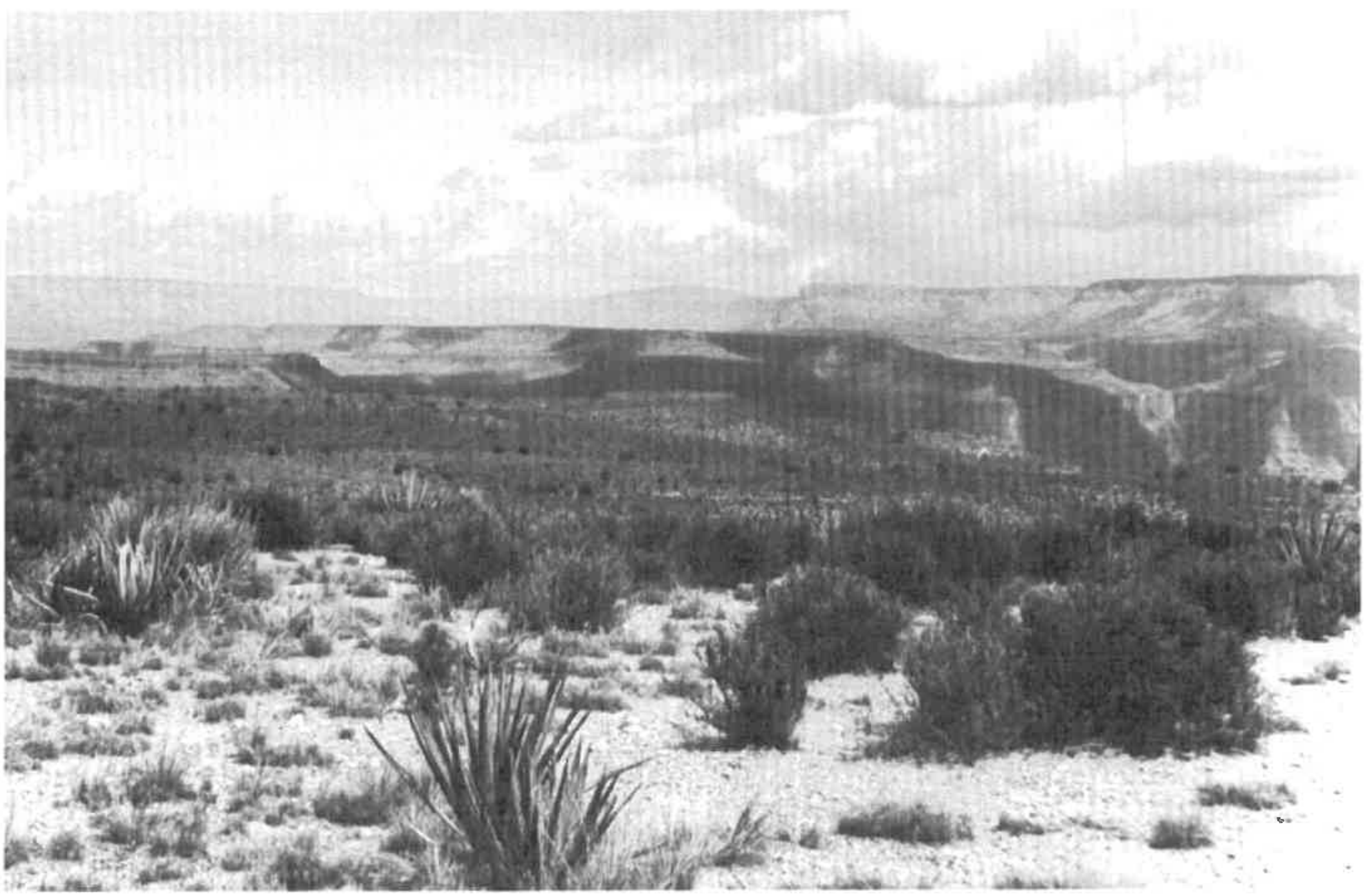


Figure 6.—Blackbrush and yucca in MLRU 35-1AZ. The foreground is the Curhollow soil in an area of Curhollow-Rolle-Meriwhitica association, 1 to 35 percent slopes. The background shows plateaus and mesas typical of the area.

Figure 7.—Ponderosa pine in an area of Turkeytrack gravelly loam, 1 to 6 percent slopes, in MLRU 39-1AZ.

sagebrush, and mountain big sagebrush.

This MLRU is used for commercial timber cutting. It is also used for recreational purposes, such as hiking, camping, fishing, and hunting. Additionally, this unit provides grazing for livestock during the summer months.

This MLRU makes up only about 4 percent of the survey area. The majority of the soils in this unit in the survey area are high in clay and range from very shallow to very deep. The major soils are Pinntank, Pocomate, and Theecan soils. The minor soils are Retsover and Turkeytrack soils on mesas and Pinespring and Sponiker soils in draws and on stream terraces.

Geologic History

The northern edge of the survey area contains an extensive geologic record expressed within the deeply entrenched Grand Canyon. The Grand Canyon is unique, not only because of its scenic beauty but also because it is the most complete and well preserved stratigraphic column in the world. From the bottom of the canyon to the top, the different layers of rock represent the history of the earth from about 2 billion years ago to the present day. Figure 8 shows a complete stratigraphic section of the Grand Canyon on the northern edge of the survey area.

The first rocks on the earth's surface formed about 4 billion years ago in the Precambrian Period. At this time, the continents were merely thin crusts of rock floating on a magma ocean. Eventually, when the earth cooled and moisture condensed, the rock began to weather. The first eroded sediments were formed into rock about 2 billion years ago as the result of heat and pressure over time. The hardened sediments were uplifted, tilted, and exposed to further heat and pressure. These altered, or metamorphic, rocks of Precambrian age are exposed in the bottom of the Grand Canyon and lower Peach Springs Canyon. These rocks are called the Vishnu Group and consist of schist and gneiss with granitic intrusions.

About 600 to 500 million years ago, the Precambrian age continents were covered by shallow seas. Sediments deposited during advancement and recession of the Cambrian age seas formed the Tapeats Sandstone, Bright Angel Shale, and the Muav Limestone formations of the Tonto Group. These rocks can be seen in the lower reaches of Peach Springs Canyon.

There are no rocks in the Grand Canyon formed during the Ordovician Period (500 to 400 million years ago) or the Silurian Period (440 to 400 million years ago). One theory is that the area was no longer under water and no sediments were deposited or the deposited sediments were eroded away. The lack of sediment deposition is called a hiatus and is an unconformity in the stratigraphic column (Collier, 1980).

About 400 million years ago this area was again invaded by shallow seas. Devonian age sediments, which formed the Temple Butte Limestone, were deposited. Following the Devonian Period, a hiatus in deposition occurred for about 150 million years. Then about 350 to 325 million years ago, this area was submerged again during the Mississippian Period. Fossils indicate that this area was a shallow, warm, tropical sea. Calcium carbonate and other sediments deposited in this area formed the Redwall Limestone that consistently forms massive, vertical cliffs 500 to 800 feet high about midway up the canyon wall. The cliff face is usually stained red by iron oxide material washed down from the red beds of the overlying Supai Group.

During the Pennsylvanian and early Permian Periods, 325 to 300 million years ago, four formations of the Supai Group were deposited in a low, swampy environment of continental, shoreline, and shallow marine origin. A broad variety of lithologies including sandstone, mudstone, conglomerate, and limestone occur in this group and contain a large amount of iron oxide, which imparts a tan to bright red color that is characteristic of these formations. The four formations, in ascending order, are the Watahomigi, the Manakacha, the Wescogame, and the Esplanade Sandstone Formations. The Esplanade Sandstone Formation forms a broad flat terrace, called a structural bench, that is located midway up the canyon (Harris and Tuttle, 1983).

In ascending order, the Hermit Shale, Coconino Sandstone, Toroweap Formation, and Kaibab Limestone were all deposited during the Permian Period, 280 to 240 million years ago (Nations and Stump, 1981). The Hermit Shale was deposited in a low, swampy environment and is composed of red sloping, erodible siltstones. The Coconino Sandstone formed from desert sand dunes. It exhibits strong crossbedding in tan and buff vertical cliffs below the canyon rim. The overlying Toroweap Formation consists of sloping beds of sandstone, limestone, and gypsum. It marks the advance and recession of a western sea. The uppermost Kaibab Limestone was deposited by the return of this western sea. Its tan cliffs and ledges comprise the uppermost layer of the Grand Canyon rock sequence. The Kaibab Limestone underlies much of the surface of the Coconino Plateau in the eastern parts of the survey area.

Additional rock formations were deposited in the Grand Canyon area during the Triassic, Jurassic, and Cretaceous Periods (240 to 63 million years ago). However, these layers have been eroded from the surface. It is estimated that more than 4,000 feet of material has been removed as a result of extensive erosion since Cretaceous time (Breed and Roat, 1974). In the western part of the survey area, the Pennsylvanian and Permian rocks have also been removed, exposing the Redwall Limestone and Muav Limestone as surface rock on the Hualapai Plateau.

The entire region was uplifted with very little deformation during Miocene time (20 million years ago). The survey area is located on a large part of this uplifted crust known as the Colorado Plateau.

During the last several million years the Colorado River and its tributaries have been cutting into the underlying rock, forming the presently entrenched Grand Canyon. The ancestral Colorado River may have flowed in its present course as far as the eastern end of the Grand Canyon, and then it either continued southeastward along the present course of the Little Colorado River or it crossed the Kaibab Plateau along its present course.

The uplifting of the Colorado Plateau caused cracks in

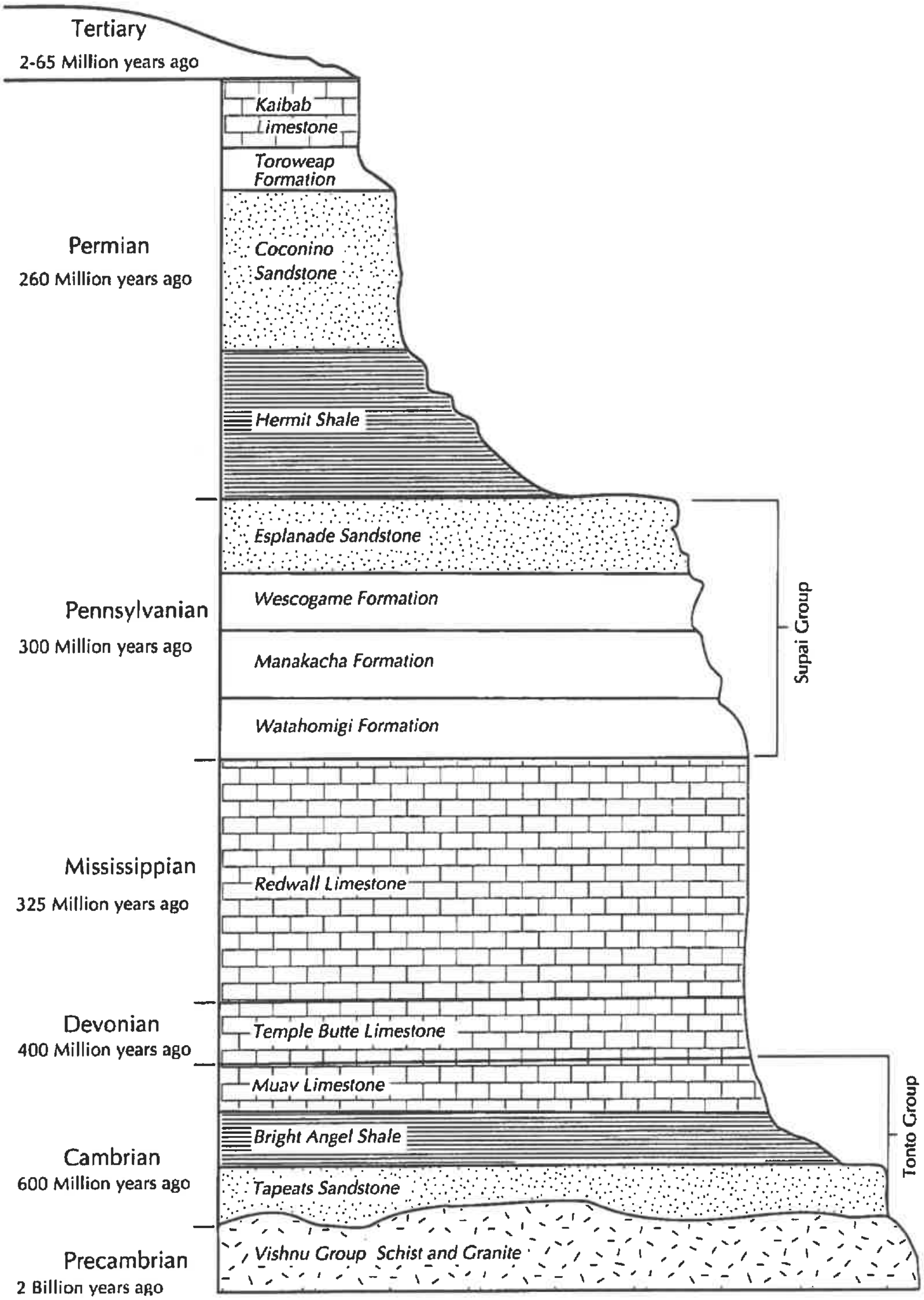


Figure 8.—Stratigraphic column of the Grand Canyon exhibiting the major geologic formations in the survey area.

the earth's crust that produced conditions conducive to volcanism all over the southwestern United States. Volcanism began about 3 million years ago with a few cinder cones in the northeastern part of the Hualapai Reservation and extensive lava flows in the western part.

Important Tertiary age formations are alluvial in origin. They include the Music Mountain Conglomerate, the Willow Springs Formation, the Buck and Doe

Conglomerate, and the Frazier Well Gravels. These formations occur mostly in the southern and western parts of the Hualapai Reservation (Young, 1966).

The most recent sedimentary deposits in the survey area are Quaternary in age and range from recently deposited sediments to sediments that are about 2 million years old. These deposits include alluvium in stream terraces, flood plains, alluvial fans, and fan terraces.

How This Survey Was Made

This survey was made to provide information about the soils and miscellaneous areas in the survey area. The information includes a description of the soils and miscellaneous areas and their location and a discussion of their suitability, limitations, and management for specified uses. Soil scientists observed the steepness, length, and shape of slopes; the general pattern of drainage; the kinds of crops and native plants; and the kinds of bedrock. They dug many holes to study the soil profile, which is the sequence of natural layers, or horizons, in a soil. The profile extends from the surface down into the unconsolidated material in which the soil formed. The unconsolidated material is devoid of roots and other living organisms and has not been changed by other biological activity.

The soils and miscellaneous areas in the survey area are in an orderly pattern that is related to the geology, landforms, relief, climate, and natural vegetation of the area. Each kind of soil and miscellaneous area is associated with a particular kind of landform or with a segment of the landform. By observing the soils and miscellaneous areas in the survey area and relating their position to specific segments of the landform, a soil scientist develops a concept, or model, of how the soils were formed. Thus, during mapping, this model enables the soil scientist to predict with a considerable degree of accuracy the kind of soil or miscellaneous area at a specific location on the landscape.

Commonly, individual soils on the landscape merge into one another as their characteristics gradually change. To construct an accurate soil map, however, soil scientists must determine the boundaries between the soils. They can observe only a limited number of soil profiles. Nevertheless, these observations, supplemented by an understanding of the soil-vegetation-landscape relationship, are sufficient to verify predictions of the kinds of soil in an area and to determine the boundaries.

Soil scientists recorded the characteristics of the soil profiles that they studied. They noted color, texture, size and shape of soil aggregates, kind and amount of rock fragments, distribution of plant roots, reaction, and other features that enable them to identify soils. After describing the soils in the survey area and determining their properties, the soil scientists assigned the soils to taxonomic classes (units). Taxonomic classes are concepts. Each taxonomic class has a set of soil characteristics with precisely defined limits. The classes are used as a basis for comparison to classify soils systematically. Soil taxonomy, the system of taxonomic classification used in the United States, is based mainly on the kind and character of soil properties and the arrangement of horizons within the profile. After the soil scientists classified and named the soils in the survey area, they compared the individual soils with similar soils in the same taxonomic class in other areas so that they could confirm data and assemble additional data based on experience and research.

While a soil survey is in progress, samples of some of the soils in the area generally are collected for laboratory analyses and for engineering tests. Soil scientists interpret the data from these analyses and tests as well as the field-observed characteristics and the soil properties to determine the expected behavior of the soils under different uses. Interpretations for all of the soils are field tested through observation of the soils in different uses and under different levels of management. Some interpretations are modified to fit local conditions, and some new interpretations are developed to meet local needs. Data are assembled from other sources, such as research information, production records, and field experience of specialists. For example, data on crop yields under defined levels of management are assembled from farm records and from field or plot experiments on the same kinds of soil.

Predictions about soil behavior are based not only on soil properties but also on such variables as climate and biological activity. Soil conditions are predictable over long periods of time, but they are not predictable from year to year. For example, soil scientists can predict with a fairly high degree of accuracy that a given soil will have a high water table within certain depths in most years, but they cannot predict that a high water table will always be at a specific level in the soil on a specific date.

After soil scientists located and identified the significant natural bodies of soil in the survey area, they drew the boundaries of these bodies on aerial photographs and identified each as a specific map unit. Aerial photographs show trees, buildings, fields, roads, and rivers, all of which help in locating boundaries accurately.

The descriptions, names, and delineations of the soils in this survey area do not fully agree with those of the soils in adjacent survey areas. Differences are the result of a better knowledge of soils, modifications in series concepts, or variations in the intensity of mapping or in the extent of the soils in the survey areas.

Map Unit Composition

A map unit delineation on a soil map represents an area dominated by one major kind of soil or an area dominated by several kinds of soil. A map unit is identified and named according to the taxonomic classification of the dominant soil or soils. Within a taxonomic class there are precisely defined limits for the properties of the soils. On the landscape, however, the soils are natural objects. In common with other natural objects, they have a characteristic variability in their properties. Thus, the range of some observed properties may extend beyond the limits defined for a taxonomic class. Areas of soils of a single taxonomic class rarely, if ever, can be mapped without including areas of soils of other taxonomic classes. Consequently, every map unit is made up of the soil or soils for which it is named and some soils that belong to other taxonomic classes. These latter soils that belong to other taxonomic classes are called inclusions or included soils.

Most inclusions have properties and behavioral patterns similar to those of the dominant soil or soils in the map unit, and thus they do not affect use and management. These are called noncontrasting (similar) inclusions. They may or may not be mentioned in the map unit descriptions. Other inclusions, however, have properties and behavior divergent enough to affect use or require different management. These are contrasting (dissimilar) inclusions. They generally occupy small areas and cannot be shown separately on the soil maps because of the scale used in mapping. The inclusions of contrasting soils are mentioned in the map unit descriptions. A few inclusions may not have been observed and consequently are not mentioned in the descriptions, especially where the soil pattern was so complex that it was impractical to make enough observations to identify all of the kinds of soil on the landscape.

The presence of inclusions in a map unit in no way diminishes the usefulness or accuracy of the soil data. The objective of soil mapping is not to delineate pure taxonomic classes of soils but rather to separate the landscape into segments that have similar use and management requirements. The delineation of such landscape segments on the map provides sufficient information for the development of resource plans, but onsite investigation is needed to plan for intensive uses in small areas.

Formation of the Soils

Processes of Soil Formation

Soils are dynamic, natural bodies on the earth's surface that are capable of supporting terrestrial plants. They are composed of mineral and organic constituents, as well as dilute solutions, gaseous mixtures, and micro-organisms. Soils are dynamic in that they exist as the result of a combination of processes occurring in the environment and they respond to changes in the environment. Some responses are immediate, such as water content and micro-organism activity after a rain. Some responses take a great deal of time to be detectable, such as the development of soil morphology.

Differences in soil morphology are expressed by differences in horizontal layers in the soil called horizons. Pedogenic soil horizons form primarily as the result of eluviation and illuviation. Eluviation is the process in which materials are leached out of a horizon by infiltrating water. Illuviation is the process in which materials have accumulated below the surface as the result of deposition from the leaching water. The soil materials on the surface and close to the surface are the most susceptible to being leached by water. These horizons lose clay, calcium carbonate, and other materials that were originally in the sediment at the time of deposition. If conditions are suitable, organic matter will accumulate in surface horizons as the result of plant growth and decomposition. Sometimes calcareous dust and other materials are deposited on the soil surface as wind blown material. These materials are also leached of various constituents. As materials are leached out of the surface horizons, they accumulate at various depths in the soil profile below the surface. Thus clay, calcium carbonate, and other materials accumulate in the subsoil in much higher concentrations than were present in the original sediment. It is these zones of leaching and accumulation that define pedogenic soil horizons and determine how the soil is classified. Important pedogenic soil horizons are defined in the Glossary.

Some soils may have horizons that are not pedogenic. Such horizons in a soil profile may have differing physical and chemical characteristics. They have not formed as the result of pedogenic processes but are the result of geologic processes such as flooding or landslides. Nonpedogenic soil horizons usually indicate a young soil. Well developed pedogenic soil horizons usually indicate an old soil. In areas of active deposition, such as flood plains, a soil that is old enough to have developed pedogenic soil horizons may be buried by a younger sediment. These soils are called buried soils or paleosols.

Factors of Soil Formation

There are five environmental factors that affect soil formation. These factors are parent material, climate, living organisms, topography, and time. Tremendous diversity exists in soil morphology as a result of unique combinations of these factors. Soil horizons are constantly forming or changing in response to these environmental factors over time. All of the factors are related, and no individual factor can completely determine a soil property. The factors are discussed in the following sections.

Parent Material

Parent material is the mineral and organic material in which soils form. It can be derived in place from weathered bedrock or transported by wind, water, or gravity. The influence of parent material is accounted for in soil taxonomy by mineralogy and particle size classes. Criteria for each class is defined in Soil Taxonomy (USDA, 1975).

Residuum is the unconsolidated mineral material that accumulates in place as bedrock disintegrates. The kind of rock from which the residuum has been weathered greatly determines the properties and characteristics of a soil formed in it. Residuum derived from sandstone usually has large amounts of sand. Parent materials derived from shale have large amounts of clay and low amounts of sand. Many types of shale may contain large amounts of sodium, gypsum, or sulphur bearing minerals. These parent materials can cause many problems for all kinds of soil uses. Basalt rocks usually form soils that have large amounts of clay. Limestone rocks form residuum that has variable amounts of clay depending on the composition of the rock.

Alluvium is unconsolidated sediment deposited by water. It includes deposits made by rivers, creeks, and intermittent streams and materials at the base of mountains forming alluvial fans, fan terraces, and bajadas.

Colluvium is material transported by gravity. Materials sloughed downhill as the result of landslides are one example of colluvium. On steep mountain slopes, materials may slowly creep downhill even if abundant vegetation exists. Occasionally, trees may even bend downslope as the result of soil creep.

Eolian materials are materials transported by wind. In the survey area, eolian deposits are very thin and commonly overlie other parent materials in many locations.

Most of the map units in the survey area contain soils formed in alluvium on stream terraces, flood plains, alluvial fans, and fan terraces. Most of the soils on stream terraces and flood plains are very deep, but many of the soils on fan terraces and plateaus are shallow or moderately deep to an indurated, calcium carbonate cemented hardpan or bedrock. Examples of soils formed in alluvium on fan terraces are Havasupai and Milkweed soils. Examples of soils formed in alluvium on stream terraces and flood plains are Cowan family, Jacques, Arizo, Lostman, and Naha soils. Natank soils are an example of a plateau soil derived from local alluvium.

Parent material can influence the development of soil horizons. Several map units in the survey area are comprised of soils formed in residuum. It is postulated that the variable porosity of the Kaibab Limestone is related to the presence or absence of argillic horizons (zones of secondary clay accumulation) in the survey area. In areas where the limestone has been leached of calcium carbonate, a porous crystal framework that is conducive to clay illuviation results. In areas where the limestone is more compacted, the nonporous bedrock inhibits the removal of calcium carbonate, which in turn retards the development of argillic horizons (Levine and Hendricks, 1989). Examples of soils formed in the Kaibab Limestone are Yumtheska and Pinntank soils. Soils formed in the Redwall Limestone are Curhollow and Meriwhitica soils.

A few of the soils in the survey area formed in residuum derived from volcanic rock. These are Prieta, Wyva, Luzena, and Thunderbird soils. Wukoki and Lomaki soils formed in volcanic cinders and are very deep. Some map units consist of soils formed in colluvium derived from formations exposed on steep canyon walls. Examples of these soils are Tovar and Hermshale soils.

Climate

Climate, past and present, has a strong effect on soil formation. Temperature and moisture affect the weathering of parent material, the activity of micro-organisms, and the release, leaching, and accumulation of nutrients. Climate also influences the plant community growing on the soil, which in turn influences soil development. Wind and water can transport soil material over long distances. Solar radiation affects soil moisture retention, temperature, and oxidation of surface organic matter. In general, weathering processes increase with increasing temperature and moisture. In the survey area, the vegetative biomass and the organic matter content of the soil increase with elevation and corresponding precipitation.

Climate is used to classify soils based on the temperature and moisture regime in which they occur. A soil temperature regime is based on the mean annual temperature of the soil at a depth of 50 centimeters. If bedrock or another hard layer occurs at a depth of less than 50 centimeters, the temperature used is the average at the top of the bedrock or hard layer. The average annual soil temperature in the survey area is about 2 degrees warmer than the average annual air temperature. For example, a mesic soil temperature regime means that the mean annual soil temperature is not lower than 8 degrees C or higher than 15 degrees C.

Soil moisture regimes are based on the amount of time that the soil profile is moist and the time of year that rainfall occurs. Generally, if the soil is dry most of the year, the soil has an aridic moisture regime. If the soil is frequently moist in most years and the rainfall occurs mostly during the growing season, the soil has an ustic moisture regime. If the soil is frequently moist and the precipitation occurs in the winter when plant growth is minimal, the soil has a xeric moisture regime. Intergrades are allowed, such as aridic-xeric or ustic-aridic. These are defined in Soil Taxonomy. The mean soil temperature and the amount of precipitation is given for each soil and each map unit in the detailed descriptions.

The present climate of the Hualapai and Havasupai Reservations is semi-arid. The variation in precipitation and temperature is directly related to differences in elevation.

The warmest and driest areas are in the canyon bottoms. They have a mean annual precipitation of 8 to 12 inches and a mean annual soil temperature of 60 to 70 degrees F. Elevations are typically less than 5,000 feet. The soil climate class in the canyons is aridic and thermic. Examples of soils in this climate class are Nickel family, Splanod, and Arizo soils.

Precipitation increases and temperature decreases on the higher surfaces of the Hualapai and Coconino Plateaus. At elevations of about 5,100 to 6,100 feet, precipitation ranges from 10 to 14 inches and average annual soil temperature is commonly 54 to 58 degrees F. Soils in this region have ustic-aridic moisture regimes and mesic temperature regimes. Examples are Winona, Tusayan, Curhollow, and Puertecito soils.

At elevations of about 4,000 to 7,200 feet, precipitation increases and soil temperature decreases slightly.

Precipitation ranges from to 14 to 18 inches, and soil temperature ranges from 48 to 58 degrees F. Soil climate is classified as aridic-ustic and mesic. Examples are Bleumont, Natank, and Frazwell soils.

The highest elevations, 6,200 to more than 7,900 feet, receive an average of 18 to 20 inches of precipitation per year and have mean annual soil temperatures of 45 to 54 degrees F. These soils have ustic moisture regimes and mesic temperature regimes. Examples are Theecan and Pinntank soils.

Past climate has also played a major role in the formation of soils in the survey area. Paleosols that developed during wetter periods occur as both relict and buried features. Examples of these soils are Bleumont and Milkweed soils, which have highly developed pedogenic horizons of clay and lime accumulation.

Living Organisms

Living organisms that influence soil development include micro-organisms and plants and animals. Within the soil, the life processes of bacteria and fungi decompose organic matter and minerals to release carbon dioxide, nitrogen, and other essential nutrients to plants. Insects and worms burrow into the soil, redistributing soil material and creating channels for air and water movement. At the soil surface, animals trample and mix soil material, add and bury organic debris, and burrow into the ground.

Plants are the major influence of living organisms on soil formation. They provide a source of organic matter, create pores and channels with roots, protect soil from erosion, and influence physical and chemical soil properties with their decomposed residue. Distinct plant communities are found at every elevation in the survey area due to differences in moisture, temperature, and kind of soil.

In the aridic thermic soils of the canyons, vegetation consists dominantly of desert shrubs, cacti, and grasses. Biomass production is low and soils are typically light colored and low in organic matter content. Examples are Arizo, Lostman, and Naha soils. Small areas of riparian communities exist along water sources, which have water tables that are within reach of roots.

The ustic-aridic mesic soils of the plateaus dominantly support grasslands. Fibrous root systems add organic matter to the soil as they decompose, darkening the soil color significantly. Juniper and pinyon woodlands that are low in production occur on shallow, rocky soils. The deep tap roots work through fractures in the underlying bedrock. Examples of such soils are Plaintank, Winona, Barx, Curhollow, and Poley soils.

At the higher elevations, pinyon-juniper woodlands and grasslands with sagebrush occur on aridic-ustic mesic soils. The sagebrush and grass vegetation add significant amounts of organic matter to the soil. In some soils mollic epipedons may have formed. These surface soil horizons have large amounts of organic matter and very dark colors. Examples of soils with mollic epipedons are Frazwell and Yumtheska soils.

Ponderosa pine forest grows in the highest elevations on ustic mesic soils. Mollic epipedons are common in level and concave landscape positions. Layers of clay accumulation in the subsoil called argillic horizons are well developed and often underlie a thin eluvial horizon. Acidic pine litter influences leaching processes and soil reaction. Organic acids have leached the upper subsoils of calcium carbonate even though they developed in limestone parent material. Examples are Pinntank and Retsover soils.

Topography

Topography influences soil development through its effect upon water movement and stability of soil material. Steep slopes increase surface water runoff and water erosion. Soils on steep and very steep slopes are often unstable, and water erosion occurs faster than the processes of soil development. Wind erosion is also significant in the survey area. Soils on steep slopes are commonly shallow and have poorly developed soil horizons. Many of these soils occur on canyon walls and escarpments. Examples are Metuck, Meriwhitica, and Hindu soils. Some of the soils on the very steep canyon walls are so variable that it is not possible to classify them into a specific series. They are called Torriorthents or Ustorthents, depending on their soil moisture regime.

Soils on the lesser slopes tend to be more stable and develop distinct soil horizons over time. Surface runoff collects in level to concave areas from adjoining uplands, where organic matter and sediments accumulate. In these areas of alluvial deposition, the surface horizons are somewhat thicker and higher in organic matter and may form mollic epipedons. For example, Frazwell soils are very deep soils that occur in slightly concave positions. They have a thick dark surface layer that is rich in organic matter and is derived from adjacent slopes. Natank soils are another example of stability. They have developed a strong horizon of clay accumulation over long periods of time.

Time

Time as a soil forming factor refers to the duration that a parent material has been in place and influenced by the other soil forming factors. Generally, the older and more stable a soil is, the more developed the morphology will be. For example, unprotected soils on steep slopes and soils in active flood plains are unstable and subject to erosion. Therefore, they are generally young soils. They have few, if any, pedogenic soil horizons.

Examples of very young soils are Arizo soils and Cowan family soils. They do not have pedogenic soil horizons. They have different layers in their soil profiles, but the layers are the result of geologic deposition. These soils occur in very active and unstable environments such as flood plains and alluvial fans. In these areas erosion and deposition occur so frequently that time is insufficient for the soil forming factors to form pedogenic soil horizons.

Bleumont soils are an example of a very old soil. These soils formed in alluvium on fan terraces. They have horizons that are high in clay and calcium carbonate. These layers formed as the result of pedogenic processes over long periods of time.

Most soils result from the interaction of all five of the soil forming factors. Some soils on the modern landscape actually formed under different climatic or vegetative conditions of the past. The diversity of soil types in the survey area expresses the complexity of the environmental factors that influenced their development.

Glossary

Aeration, soil. The exchange of air in soil with air from the atmosphere. The air in a well aerated soil is similar to that in the atmosphere; the air in a poorly aerated soil is considerably higher in carbon dioxide and lower in oxygen.

Aggregate, soil. Many fine particles held in a single mass or cluster. Natural soil aggregates, such as granules, blocks, or prisms, are called peds. Clods are aggregates produced by tillage or logging.

Alkali (sodic) soil. A soil having so high a degree of alkalinity (pH 8.5 or higher), or so high a percentage of exchangeable sodium (15 percent or more of the total exchangeable bases), or both, that plant growth is restricted.

Alluvium. Material, such as sand, silt, or clay, deposited on land by streams.

Alluvial fan. The fanlike deposit of a stream where it issues from a gorge upon a plain or of a tributary stream near or at its junction with its main stream.

Animal-unit-month (AUM). The amount of forage required by one mature cow of approximately 1,000 pounds weight, with or without calf, for 1 month.

Area reclaim (in tables). An area difficult to reclaim after the removal of soil for construction and other uses. Revegetation and erosion control are extremely difficult.

Association, soil. A group of soils geographically associated in a characteristic repeating pattern and defined and delineated as a single map unit.

Available water capacity (available moisture capacity). The capacity of soils to hold water available for use by most plants. It is commonly defined as the difference between the amount of soil water at field moisture capacity and the amount at wilting point. It is commonly expressed as inches of water per inch of soil. The capacity, in inches, in a 60-inch profile or to a limiting layer is expressed as:

Very low	0 to 2.5
Low	2.5 to 5.0
Moderate	5.0 to 7.5
High	7.5 to 10.0
Very high	more than 10.0

Back slope. The geomorphic component that forms the steepest inclined surface and principal element of many hillsides. Back slopes in profile are commonly steep, are linear, and may or may not include cliff segments.

Basalt. Igneous rock formed by the cooling and hardening of a magma associated with volcanic activity and emplaced at or near the earth's surface.

Bedding planes. Fine stratifications, less than 5 millimeters thick, in unconsolidated alluvial, eolian, lacustrine, or marine sediments.

Bedrock. The solid rock that underlies the soil and other unconsolidated material or that is exposed at the surface.

Bottom land. The normal flood plain of a stream, subject to flooding.

Boulders. Rock fragments larger than 2 feet (60 centimeters) in diameter.

Breaks. The steep to very steep broken land at the border of an upland summit that is dissected by gullies.

Brush management. Use of mechanical, chemical, or biological methods to reduce or eliminate competition of woody vegetation to allow understory grasses and forbs to recover, or to make conditions favorable for reseeding. It increases production of forage, which reduces erosion. Brush management may improve the habitat for some species of wildlife.

Calcareous soil. A soil containing enough calcium carbonate (commonly combined with magnesium carbonate) to effervesce visibly when treated with cold, dilute hydrochloric acid.

Canopy. The leafy crown of trees or shrubs.

Canyon. A long, deep, narrow, very steep sided valley with high, precipitous walls in an area of high local relief.

Capillary water. Water held as a film around soil particles and in tiny spaces between particles. Surface tension is the adhesive force that holds capillary water in the soil.

Cation. An ion carrying a positive charge of electricity. The common soil cations are calcium, potassium, magnesium, sodium, and hydrogen.

Cation-exchange capacity. The total amount of exchangeable cations that can be held by the soil, expressed in terms of milliequivalents per 100 grams of soil at neutrality (pH 7.0) or at some other stated pH value. The term, as applied to soils, is synonymous with base-exchange capacity but is more precise in meaning.

Channer. A thin, flat rock fragment as much as 6 inches along the longest axis.

Channery soil material. A soil that is, by volume, 15 to 35 percent thin, flat rock fragments as much as 6 inches along the longest axis. Very channery soil material is 35 to 60 percent of these rock fragments, and extremely channery soil material is more than 60 percent.

Clay. As a soil separate, the mineral soil particles less than 0.002 millimeter in diameter. As a soil textural class, soil material that is 40 percent or more clay, less than 45 percent sand, and less than 40 percent silt.

Clay film. A thin coating of oriented clay on the surface of a soil aggregate or lining pores or root channels. Synonyms: clay coating, clay skin.

Climax vegetation. The stabilized plant community on a particular site. The plant cover reproduces itself and does not change so long as the environment remains the same.

Coarse fragments. If round, mineral or rock particles 2 millimeters to 25 centimeters (10 inches) in diameter; if flat, mineral or rock particles (flagstone) 15 to 38 centimeters (6 to 15 inches) long.

Coarse textured soil. Sand or loamy sand.

Cobblestone (or cobble). A rounded or partly rounded fragment of rock 3 to 10 inches (7.5 to 25 centimeters) in diameter.

Colluvium. Soil material, rock fragments, or both moved by creep, slide, or local wash and deposited at the base of steep slopes.

Complex, soil. A map unit of two or more kinds of soil in such an intricate pattern or so small in area that it is not practical to map them separately at the selected scale of mapping. The pattern and proportion of the soils are somewhat similar in all areas.

Concretions. Grains, pellets, or nodules of various sizes, shapes, and colors consisting of concentrated compounds or cemented soil grains. The composition of most concretions is unlike that of the surrounding soil. Calcium carbonate and iron oxide are common compounds in concretions.

Conglomerate. A coarse grained, clastic rock composed of rounded to subangular rock fragments more than 2 millimeters in diameter. It commonly has a matrix of sand and finer material. Conglomerate is the consolidated equivalent of gravel.

Consistence, soil. The degree of cohesion among soil particles and the adhesion of soil to other substances. Consistence is described in terms of the soil's resistance to cracking or breaking when force is applied, the amount of force required to deform but not rupture soil material, and the degree to which soil material adheres to other objects.

Loose.—Noncoherent when dry or moist; does not hold together in a mass.

Firm.—When moist, crushes under moderate pressure between thumb and forefinger, but resistance indistinctly noticeable.

Friable.—When moist, crushes easily under gentle pressure between thumb and forefinger and can be pressed together into a lump.

Plastic.—When wet, readily deformed by moderate pressure but can be pressed into a lump; will form a "wire" when rolled between thumb and forefinger.

Sticky.—When wet, adheres to other material and tends to stretch somewhat and pull apart rather than to pull free from other material.

Hard.—When dry, moderately resistant to pressure; can be broken with difficulty between thumb and forefinger.

Soft.—When dry, breaks into powder or individual grains under very slight pressure.

Control section. The part of the soil on which classification is based. The thickness varies among different kinds of soil, but for many it is that part of the soil profile between depths of 10 inches and 40 or 80 inches.

Corrosivity. The potential or risk of corrosion to uncoated steel or deterioration of concrete.

Cretaceous. The third portion of the Mesozoic Era of geologic time (from approximately 135 to 65 million years ago).

Cutbanks cave (in tables). The walls of excavations tend to cave in or slough.

Decreasers. The most heavily grazed climax range plants. Because they are the most palatable, they are the first to be destroyed by overgrazing.

Deferred grazing. Postponing grazing or resting grazing land for a prescribed period.

Depth to rock (in tables). Bedrock is too near the surface for the specified use.

Dip slope. A slope of the land surface, roughly determined by and approximately conforming with the dip of underlying bedded rock.

Drainage class (natural). Refers to the frequency and duration of periods of saturation or partial saturation during soil formation, as opposed to altered drainage, which is commonly the result of artificial drainage or irrigation but may be caused by the sudden deepening of channels or the blocking of drainage outlets. Seven classes of natural soil drainage are recognized:

Excessively drained.—Water is removed from the soil very rapidly. Excessively drained soils are commonly very coarse textured, rocky, or shallow. Some are steep. All are free of the mottling related to wetness.

Somewhat excessively drained.—Water is removed from the soil rapidly. Many somewhat excessively drained soils are sandy and rapidly pervious. Some are shallow. Some are so steep that much of the water they receive is lost as runoff. All are free of the mottling related to wetness.

Well drained.—Water is removed from the soil readily, but not rapidly. It is available to plants throughout most of the growing season, and wetness does not inhibit growth of roots for significant periods during most growing seasons. Well drained soils are commonly medium textured. They are mainly free of mottling.

Moderately well drained.—Water is removed from the soil somewhat slowly during some periods. Moderately well drained soils are wet for only a short time during the growing season, but periodically they are wet long enough that most mesophytic crops are affected. They commonly have a slowly pervious layer within or directly below the solum, or periodically receive high rainfall, or both.

Somewhat poorly drained.—Water is removed slowly enough that the soil is wet for significant periods during the growing season. Wetness markedly restricts the growth of mesophytic crops unless artificial drainage is provided. Somewhat poorly drained soils commonly have a slowly pervious layer, a high water table, additional water from seepage, nearly continuous rainfall, or a combination of these.

Poorly drained.—Water is removed so slowly that the soil is saturated periodically during the growing season or remains wet for long periods. Free water is commonly at or near the surface for long enough during the growing season that most mesophytic crops cannot be grown unless the soil is artificially drained. The soil is not continuously saturated in layers directly below plow depth. Poor drainage results from a high water table, a slowly pervious layer within the profile, seepage, nearly continuous rainfall, or a combination of these.

Very poorly drained.—Water is removed from the soil so slowly that free water remains at or on the surface during most of the growing season. Unless the soil is artificially drained, most mesophytic crops cannot be grown. Very poorly drained soils are commonly level or depressed and are frequently ponded. Yet, where rainfall is high and nearly continuous, they can have moderate or high slope gradients.

Drainage, surface. Runoff, or surface flow of water, from an area.

Draw. A small stream valley, generally more open and with broader bottom land than a ravine or gully.

Duff. A term used to identify a generally firm organic layer on the surface of mineral soils. It consists of fallen plant material that is in the process of decomposition and includes everything from the litter on the surface to underlying pure humus.

Eluviation. The movement of material in true solution or colloidal suspension from one place to another within the soil. Soil horizons that have lost material through eluviation are eluvial; those that have received material are illuvial.

Eolian soil material. Earthy parent material accumulated through wind action; commonly refers to sandy material in dunes or to loess in blankets on the surface.

Ephemeral stream. A stream, or reach of a stream, that flows only in direct response to precipitation. It receives no long-continued supply from melting snow or other source, and its channel is above the water table at all times.

Erosion. The wearing away of the land surface by water, wind, ice, or other geologic agents and by such processes as gravitational creep.

Erosion (geologic). Erosion caused by geologic processes acting over long geologic periods and resulting in the wearing away of mountains and the building up of such landscape features as flood plains and coastal plains. Synonym: natural erosion.

Erosion (accelerated). Erosion much more rapid than geologic erosion, mainly as a result of the activities of man or other animals or of a catastrophe in nature, for example, fire, that exposes the surface.

Erosion pavement. A layer of gravel or stones that remains on the surface after fine particles are removed by sheet or rill erosion.

Escarpment. A relatively continuous and steep slope or cliff breaking the general continuity of more gently sloping land surfaces and produced by erosion or faulting.

Excess fines (in tables). Excess silt and clay in the soil. The soil is not a source of gravel or sand for construction purposes.

Excess salts (in tables). Excess water-soluble salts in the soil that restrict the growth of most plants.

Extrusive rock. Igneous rock derived from deep-seated molten matter (magma) emplaced on the earth's surface.

Fan terrace. A relict alluvial fan, no longer a site of active deposition, incised by younger and lower alluvial surfaces.

Fast intake (in tables). The rapid movement of water into the soil.

Fertility, soil. The quality that enables a soil to provide plant nutrients, in adequate amounts and in proper balance, for the growth of specified plants when light, moisture, temperature, tilth, and other growth factors are favorable.

Field moisture capacity. The moisture content of a soil, expressed as a percentage of the ovendry weight, after the gravitational, or free, water has drained away; the field moisture content 2 or 3 days after a soaking rain; also called normal field capacity, normal moisture capacity, or capillary capacity.

Fine textured soil. Sandy clay, silty clay, and clay.

Flagstone. A thin flat rock fragment 6 to 15 inches (15 to 38 centimeters) long.

Flaggy soil material. Material that is, by volume, 15 to 35 percent flagstones. Very flaggy soil material is 35 to 60 percent flagstones, and extremely flaggy soil material is more than 60 percent flagstones.

Flood plain. A nearly level alluvial plain that borders a stream and is subject to flooding unless protected artificially.

Fluvial. Of or pertaining to rivers; produced by river action, as a fluvial plain.

Foothill. A steeply sloping upland that has relief of as much as 1,000 feet (or 300 meters) and fringes a mountain range or high-plateau escarpment.

Foot slope. The geomorphic component that forms the inner inclined surface at the base of a hill. Foot slopes in profile are dominantly concave and may form transition zones between upslope sites of erosion (back slope) and downslope sites of deposition (toe slope).

Forb. Any herbaceous plant not a grass or a sedge.

Formation (stratigraphy). The basic rock-stratigraphic unit in the local classification of rocks. A body of rock (commonly a sedimentary stratum or strata, but also igneous and metamorphic rocks) generally characterized by some degree of internal lithologic homogeneity or distinctive lithologic features such as chemical composition, structures, textures, or general kind of fossils.

Frost action (in tables). Freezing and thawing of soil moisture. Frost action can damage roads, buildings and other structures, and plant roots.

Genesis, soil. The mode of origin of the soil. Refers especially to the processes or soil-forming factors responsible for the formation of the solum, or true soil, from the unconsolidated parent material.

Gravel. Rounded or angular fragments of rock up to 3 inches (2 millimeters to 7.6 centimeters) in diameter.

Gravelly soil material. Material that is 15 to 35 percent, by volume, rounded or angular rock fragments, not prominently flattened, up to 3 inches (7.6 centimeters) in diameter. Very gravelly soil material is 35 to 60 percent of these fragments, and extremely gravelly soil material is more than 60 percent.

Ground water (geology). Water filling all the unblocked pores of underlying material below the water table.

Gully. A miniature valley with steep sides cut by running water and through which water ordinarily runs only after rainfall. The distinction between a gully and a rill is one of depth. A gully generally is an obstacle to farm machinery and is too deep to be obliterated by ordinary tillage; a rill is of lesser depth and can be smoothed over by ordinary tillage.

Hardpan. A hardened or cemented soil horizon, or layer. The soil material is sandy, loamy, or clayey and is cemented by iron oxide, silica, calcium carbonate, or other substance.

Hard rock. Rock that cannot be excavated except by blasting or by the use of special equipment that is not commonly used in construction.

Hill. A natural elevation of the land surface, rising as much as 1,000 feet above surrounding lowlands, commonly of limited summit area and having a well-defined outline consisting of a summit, shoulder, back slope, foot slope, and toe slopes; hillsides generally have slopes of more than 15 percent. The distinction between a hill and a mountain is arbitrary and is dependent on local usage.

Holocene. The second epoch of the Quaternary Period of geologic time, extending from the end of the Pleistocene Epoch (about 10 to 12 thousand years ago) to the present.

Horizon, soil. A layer of soil, approximately parallel to the surface, having distinct characteristics produced by soil-forming processes. In the identification of soil horizons, an uppercase letter represents the major horizons. Numbers or lower case letters that follow represent subdivisions of the major horizons. The major horizons are as follows:

O horizon.—An organic layer of fresh and decaying plant residue.

A horizon.—The mineral horizon at or near the surface in which an accumulation of humified organic matter is mixed with the mineral material. Also, any plowed or disturbed surface layer.

E horizon.—The mineral horizon in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these.

B horizon.—The mineral horizon below an O, A, or E horizon. The B horizon is in part a layer of transition from the overlying horizon to the underlying C horizon. The B horizon also has distinctive characteristics, such as (1) accumulation of clay, sesquioxides, humus, or a combination of these; (2) granular, prismatic, or blocky structure; (3) redder or browner colors than those in the A horizon; or (4) a combination of these.

C horizon.—The mineral horizon or layer, excluding indurated bedrock, that is little affected by soil-forming processes and does not have the properties typical of the overlying horizon. The material of a C horizon may be either like or unlike that in which the solum formed.

If the material is known to differ from that in the solum, an Arabic numeral, commonly a 2, precedes the letter C.

Cr horizon.—Soft, consolidated bedrock beneath the soil.

R layer.—Hard, consolidated bedrock beneath the soil. The bedrock commonly underlies a C horizon but can be directly below an A or a B horizon.

Humus. The well decomposed, more or less stable part of the organic matter in mineral soils.

Hydrologic soil groups. Refers to soils grouped according to their runoff-producing characteristics. The chief consideration is the inherent capacity of soil bare of vegetation to permit infiltration. The slope and the kind of plant cover are not considered but are separate factors in predicting runoff. Soils are assigned to four groups. In group A are soils having a high infiltration rate when thoroughly wet and having a low runoff potential. They are mainly deep, well drained, and sandy or gravelly. In group D, at the other extreme, are soils having a very slow infiltration rate and thus a high runoff potential. They have a claypan or clay layer at or near the surface, have a permanent high water table, or are shallow over nearly impervious bedrock or other material. A soil is assigned to two hydrologic groups if part of the acreage is artificially drained and part is undrained.

Igneous rock. Rock formed by solidification from a molten or partially molten state. Major varieties include plutonic and volcanic rock. Examples are andesite, basalt, and granite.

Illuviation. The movement of soil material from one horizon to another in the soil profile. Generally, material is removed from an upper horizon and deposited in a lower horizon.

Impervious soil. A soil through which water, air, or roots penetrate slowly or not at all. No soil is absolutely impervious to air and water all the time.

Increasers. Species in the climax vegetation that increase in amount as the more desirable plants are reduced by close grazing. Increasers commonly are the shorter plants and the less palatable to livestock.

Infiltration. The downward entry of water into the immediate surface of soil or other material, as contrasted with percolation, which is the movement of water through soil layers or material.

Infiltration capacity. The maximum rate at which water can infiltrate into a soil under a given set of conditions.

Infiltration rate. The rate at which water penetrates the surface of the soil at any given instant, usually expressed in inches per hour. The rate can be limited by the infiltration capacity of the soil or the rate at which water is applied at the surface.

Intake rate. The average rate of water entering the soil under irrigation. Most soils have a fast initial rate; the rate decreases with application time. Therefore, intake rate for design purposes is not a constant but is a variable depending on the net irrigation application. The rate of water intake, in inches per hour, is expressed as follows:

Less than 0.2	very low
0.2 to 0.4	low
0.4 to 0.75	moderately low
0.75 to 1.25	moderate
1.25 to 1.75	moderately high
1.75 to 2.5	high
More than 2.5	very high

Intermittent stream. A stream, or reach of a stream, that flows for prolonged periods only when it receives ground water discharge or long, continued contributions from melting snow or other surface and shallow subsurface sources.

Invaders. On range, plants that encroach into an area and grow after the climax vegetation has been reduced by grazing. Generally, invader plants follow disturbance of the surface.

Irrigation. Application of water to soils to assist in production of crops. Methods of irrigation are:

Basin.—Water is applied rapidly to nearly level plains surrounded by levees or dikes.

Border.—Water is applied at the upper end of a strip in which the lateral flow of water is controlled by small earth ridges called border dikes, or borders.

Controlled flooding.—Water is released at intervals from closely spaced field ditches and distributed uniformly over the field.

Corrugation.—Water is applied to small, closely spaced furrows or ditches in fields of close-growing crops or in orchards so that it flows in only one direction.

Drip (or trickle).—Water is applied slowly and under low pressure to the surface of the soil or into the soil through such applicators as emitters, porous tubing, or perforated pipe.

Furrow.—Water is applied in small ditches made by cultivation implements. Furrows are used for tree and row crops.

Sprinkler.—Water is sprayed over the soil surface through pipes or nozzles from a pressure system.

Subirrigation.—Water is applied in open ditches or tile lines until the water table is raised enough to wet the soil.

Wild flooding.—Water, released at high points, is allowed to flow onto an area without controlled distribution.

Jurassic. The second period of the Mesozoic Era of geologic time (from approximately 195 to 135 million years ago).

Landslide. The rapid downhill movement of a mass of soil and loose rock, generally when wet or saturated. The speed and distance of movement, as well as the amount of soil and rock material, vary greatly.

Large stones (in tables). Rock fragments 3 inches (7.6 centimeters) or more across. Large stones adversely affect the specified use of the soil.

Leaching. The removal of soluble material from soil or other material by percolating water.

Liquid limit. The moisture content at which the soil passes from a plastic to a liquid state.

Loam. Soil material that is 7 to 27 percent clay particles, 28 to 50 percent silt particles, and less than 52 percent sand particles.

Low strength. The soil is not strong enough to support loads.

Mechanical treatment. Use of mechanical equipment for seeding, brush management, and other management practices.

Medium textured soil. Very fine sandy loam, loam, silt loam, or silt.

Mesa. A broad, nearly flat topped and commonly isolated upland mass characterized by summit widths that are more than the heights of bounding erosional scarps.

Metamorphic rock. Rock of any origin altered in mineralogical composition, chemical composition, or structure by heat, pressure, and movement. Nearly all such rocks are crystalline.

Mineral soil. Soil that is mainly mineral material and low in organic material. Its bulk density is more than that of organic soil.

Miscellaneous area. An area that has little or no natural soil and supports little or no vegetation.

Moderately coarse textured soil. Coarse sandy loam, sandy loam, and fine sandy loam.

Moderately fine textured soil. Clay loam, sandy clay loam, and silty clay loam.

Morphology, soil. The physical makeup of the soil, including the texture, structure, porosity, consistence, color, and other physical, mineral, and biological properties of the various horizons, and the thickness and arrangement of those horizons in the soil profile.

Mottling, soil. Irregular spots of different colors that vary in number and size. Mottling generally indicates poor aeration and impeded drainage. Descriptive terms are as follows: abundance—*few, common*, and *many;* size—*fine, medium*, and *coarse;* and contrast—*faint, distinct*, and *prominent*. The size measurements are of the diameter along the greatest dimension. *Fine* indicates less than 5 millimeters (about 0.2 inch); *medium*, from 5 to 15 millimeters (about 0.2 to 0.6 inch); and *coarse*, more than 15 millimeters (about 0.6 inch).

Mountain. A natural elevation of the land surface, rising more than 1,000 feet above surrounding lowlands, commonly of restricted summit area (relative to a plateau) and generally having steep sides and considerable bare-rock surface. A mountain can occur as a single, isolated mass or in a group forming a chain or range.

Mudstone. Sedimentary rock formed by induration of silt and clay in approximately equal amounts.

Munsell notation. A designation of color by degrees of three simple variables—hue, value, and chroma. For example, a notation of 10YR 6/4 is a color that has hue of 10YR, value of 6, and chroma of 4.

Neutral soil. A soil having a pH value between 6.6 and 7.3. (See Reaction, soil.)

Nutrient, plant. Any element taken in by a plant essential to its growth. Plant nutrients are mainly nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper, boron, and zinc obtained from the soil and carbon, hydrogen, and oxygen obtained from the air and water.

Organic matter. Plant and animal residue in the soil in various stages of decomposition.

Parent material. The unconsolidated organic and mineral material in which soil forms.

Ped. An individual natural soil aggregate, such as a granule, a prism, or a block.

Pedon. The smallest volume that can be called "a soil." A pedon is three dimensional and large enough to permit study of all horizons. Its area ranges from about 10 to 100 square feet (1 square meter to 10 square meters), depending on the variability of the soil.

Percolation. The downward movement of water through the soil.

Percs slowly (in tables). The slow movement of water through the soil, adversely affecting the specified use.

Permeability. The quality of the soil that enables water to move downward through the profile. Permeability is measured as the number of inches per hour that water moves downward through the saturated soil. Terms describing permeability are:

Very slow	less than 0.06 inch
Slow	0.06 to 0.2 inch
Moderately slow	0.2 to 0.6 inch
Moderate	0.6 inch to 2.0 inches
Moderately rapid	2.0 to 6.0 inches
Rapid	6.0 to 20 inches
Very rapid	more than 20 inches

Phase, soil. A subdivision of a soil series based on features that affect its use and management. For example, slope, stoniness, and thickness.

pH value. A numerical designation of acidity and alkalinity in soil. (See Reaction, soil.)

Piping (in tables). Formation of subsurface tunnels or pipelike cavities by water moving through the soil.

Plasticity index. The numerical difference between the liquid limit and the plastic limit; the range of moisture content within which the soil remains plastic.

Plastic limit. The moisture content at which a soil changes from semisolid to plastic.

Plateau. An extensive upland mass with relatively flat summit area that is considerably elevated (more than 100 meters) above adjacent lowlands and separated from them on one or more sides by escarpments.

Ponding. Standing water on soils in closed depressions. Unless the soils are artificially drained, the water can be removed only by percolation or evapotranspiration.

Poorly graded. Refers to a coarse grained soil or soil material consisting mainly of particles of nearly the same size. Because there is little difference in size of the particles, density can be increased only slightly by compaction.

Poor filter (in tables). Because of rapid permeability, the soil may not adequately filter effluent from a waste disposal system.

Potential plant community. The plant community on a given site that will be established if present environmental conditions continue to prevail and the site is properly managed.

Potential rooting depth (effective rooting depth). Depth to which roots could penetrate if the content of moisture in the soil were adequate. The soil has no properties restricting the penetration of roots to this depth.

Prescribed burning. The application of fire to land under such conditions of weather, soil moisture, and time of day as presumably will result in the intensity of heat and spread required to accomplish specific forest management, wildlife, grazing, or fire hazard reduction purposes.

Productivity, soil. The capability of a soil for producing a specified plant or sequence of plants under specific management.

Profile, soil. A vertical section of the soil extending through all its horizons and into the parent material.

Proper grazing use. Grazing at an intensity that maintains enough cover to protect the soil and maintain or improve the quantity and quality of the desirable vegetation. This increases the vigor and reproduction of the key plants and promotes the accumulation of litter and mulch necessary to conserve soil and water.

Quaternary. The second period of the Cenozoic Era of geologic time, extending from the end of the Tertiary Period (about 2 million years ago) to the present, and comprising two epochs, the Pleistocene and the Holocene.

Quartzite. Metamorphic rock formed from sandstone by heat, pressure, and strong silica cementation.

Rangeland. Land on which the potential natural vegetation is predominantly grasses, grasslike plants, forbs, or shrubs suitable for grazing or browsing. It includes natural grasslands, savannas, many wetlands, some deserts, tundras, and areas that support certain forb and shrub communities.

Range condition. The present composition of the plant community on a range site in relation to the potential natural plant community for that site. Range condition is expressed as excellent, good, fair, or poor, on the basis of how much the present plant community has departed from the potential.

Range site. An area of rangeland where climate, soil, and relief are sufficiently uniform to produce a distinct natural plant community. A range site is the product of all the environmental factors responsible for its development. It is typified by an association of species that differ from those on other range sites in kind or proportion of species or total production.

Reaction, soil. A measure of acidity or alkalinity of a soil, expressed in pH values. A soil that tests to pH 7.0 is described as precisely neutral in reaction because it is neither acid nor alkaline. The degrees of acidity or alkalinity, expressed as pH values, are:

Ultra acid	below 3.5
Extremely acid	3.5 to 4.4
Very strongly acid	4.5 to 5.0
Strongly acid	5.1 to 5.5
Medium acid	5.6 to 6.0
Slightly acid	6.1 to 6.5
Neutral	6.6 to 7.3
Slightly alkaline	7.4 to 7.8
Moderately alkaline	7.9 to 8.4
Strongly alkaline	8.5 to 9.0
Very strongly alkaline	9.1 and higher

Regolith. The unconsolidated mantle of weathered rock and soil material on the earth's surface; the loose earth material above the solid rock.

Relief. The elevations or inequalities of a land surface, considered collectively.

Residuum (residual soil material). Unconsolidated, weathered or partly weathered mineral material that accumulated as consolidated rock disintegrated in place.

Rill. A steep-sided channel resulting from accelerated erosion. A rill is generally a few inches deep and not wide enough to be an obstacle to farm machinery.

Riparian. A term pertaining to plants and animals living on, or adjacent to, the bank or flood plain of an intermittent stream or perennial river.

Rippable. Bedrock or hardpan can be excavated using a single-tooth ripping attachment mounted on a tractor with a 200-300 draw bar horsepower rating.

Rock fragments. Rock or mineral fragments having a diameter of 2 millimeters or more; for example, pebbles, cobbles, stones, and boulders.

Root zone. The part of the soil that can be penetrated by plant roots.

Runoff. The precipitation discharged into stream channels from an area. The water that flows off the surface of the land without sinking into the soil is called surface runoff. Water that enters the soil before reaching surface streams is called ground-water runoff or seepage flow from ground water.

Saline soil. A soil containing soluble salts in an amount that impairs growth of plants. A saline soil does not contain excess exchangeable sodium.

Salinity. The degree to which a soil is affected by soluble salts in water. Salinity is expressed as the electrical conductivity (EC) of a saturated extract in mmhos/cm. The degrees of salinity are:

Nonsaline	Less than 2
Very slightly saline	2 to 4
Slightly saline	4 to 8
Moderately saline	8 to 16
Strongly saline	More than 16

Sand. As a soil separate, individual rock or mineral fragments from 0.05 millimeter to 2.0 millimeters in diameter. Most sand grains consist of quartz. As a soil textural class, a soil that is 85 percent or more sand and not more than 10 percent clay.

Sandstone. Sedimentary rock containing dominantly sand-sized particles.

Saprolite (soil science). Unconsolidated residual material underlying the soil and grading to hard bedrock below.

Sedimentary rock. Rock made up of particles deposited from suspension in water. The chief kinds of sedimentary rock are conglomerate, formed from gravel; sandstone, formed from sand; shale, formed from clay; and limestone, formed from soft masses of calcium carbonate. There are many intermediate types. Some wind-deposited sand is consolidated into sandstone.

Seepage (in tables). The movement of water through the soil. Seepage adversely affects the specified use.

Sequum. A sequence consisting of an illuvial horizon and the overlying eluvial horizon. (See Eluviation.)

Series, soil. A group of soils that have profiles that are almost alike, except for differences in texture of the surface layer or of the underlying material. All the soils of a series have horizons that are similar in composition, thickness, and arrangement.

Shale. Sedimentary rock formed by the hardening of a clay deposit.

Sheet erosion. The removal of a fairly uniform layer of soil material from the land surface by the action of rainfall and surface runoff.

Shoulder. The geomorphic component that forms the uppermost, inclined surface at the top of a hill. It is dominantly convex in profile and erosional in origin, and it comprises a transition zone between summits and back slopes

Shrink-swell. The shrinking of soil when dry and the swelling when wet. Shrinking and swelling can damage roads, dams, building foundations, and other structures. It can also damage plant roots.

Silica. A combination of silicon and oxygen. The mineral form is called quartz.

Silt. As a soil separate, individual mineral particles that range in diameter from the upper limit of clay (0.002 millimeter) to the lower limit of very fine sand (0.05 millimeter). As a soil textural class, soil that is 80 percent or more silt and less than 12 percent clay.

Siltstone. Sedimentary rock made up of dominantly silt-sized particles.

Site index. A designation of the quality of a forest site based on the height of the dominant stand at an arbitrarily chosen age. For example, if the average height attained by dominant and codominant trees in a fully stocked stand at the age of 50 years is 75 feet, the site index is 75 feet.

Slickensides. Polished and grooved surfaces produced by one mass sliding past another. In soils, slickensides may occur at the bases of slip surfaces on the steeper slopes; on faces of blocks, prisms, and columns; and in swelling clayey soils, where there is marked change in moisture content.

Slope. The inclination of the land surface from the horizontal. Percentage of slope is the vertical distance divided by horizontal distance, then multiplied by 100. Thus, a slope of 20 percent is a drop of 20 feet in 100 feet of horizontal distance. In this survey the following slope classes are recognized:

Nearly level	0 to 3 percent
Gently sloping or undulating	3 to 7 percent
Strongly sloping or rolling	7 to 15 percent
Moderately steep or hilly	15 to 25 percent
Steep	25 to 55 percent
Very steep	55 percent and higher

Slope (in tables). Slope is great enough that special practices are required to ensure satisfactory performance of the soil for a specific use.

Small stones (in tables). Rock fragments less than 3 inches (7.6 centimeters) in diameter. Small stones adversely affect the specified use of the soil.

Sodicity. The degree to which a soil is affected by exchangeable sodium. Sodicity is expressed as a sodium adsorption ratio (SAR) of a saturation extract, or the ratio of Na to Ca + Mg. The degrees of sodicity and their respective ratios are:

Slight	less than 13:1
Moderate	13-30:1
Strong	more than 30:1

Soil. A natural, three-dimensional body at the earth's surface. It is capable of supporting plants and has properties resulting from the integrated effect of climate and living matter acting on earthy parent material, as conditioned by relief over periods of time.

Soil separates. Mineral particles less than 2 millimeters in equivalent diameter and ranging between specified size limits. The names and sizes, in millimeters, of separates recognized in the United States are as follows:

Very coarse sand	2.0 to 1.0
Coarse sand	1.0 to 0.5
Medium sand	0.5 to 0.25
Fine sand	0.25 to 0.10
Very fine sand	0.10 to 0.05
Silt	0.05 to 0.002
Clay	less than 0.002

Solum. The upper part of a soil profile, above the C horizon, in which the processes of soil formation are active. The solum in soil consists of the A, E, and B horizons. Generally, the characteristics of the material in these horizons are unlike those of the underlying material. The living roots and plant and animal activities are largely confined to the solum.

Stone line. A concentration of coarse fragments in a soil. Generally, it is indicative of an old weathered surface. In a cross section, the line may be one fragment or more thick. It generally overlies material that weathered in place and is overlain by recent sediment of variable thickness.

Stones. Rounded and angular fragments of rock 10 to 24 inches (25 to 60 centimeters) in diameter.

Stony. Refers to a soil containing stones in numbers that interfere with or prevent tillage.

Stratified. Arranged in strata, or layers. The term refers to either soil or geologic material. Layers in soils that result from the processes of soil formation are called horizons; those inherited from the parent material are called strata.

Stream terrace. One of a series of platforms in a stream valley, flanking and more or less parallel to the stream channel, originally formed near the level of the stream, and representing the dissected remnants of an abandoned flood plain, stream bed, or valley floor produced during a former stage of erosion and deposition. Older and higher stream terraces have a relatively flat summit surface (tread), built by stream deposition, and a steep descending slope (riser), graded to a lower base level of erosion.

Structure, soil. The arrangement of primary soil particles into compound particles or aggregates. The principal forms of soil structure are—platy (laminated), prismatic (vertical axis of aggregates longer than horizontal), columnar (prisms with rounded tops), blocky (angular or subangular), and granular. Structureless soils are either single grained (each grain by itself, as in dune sand) or massive (the particles adhering without any regular cleavage, as in many hardpans).

Structural bench. A platform-type, nearly level to gently inclined erosional platform developed on resistant strata in areas where geologic erosion has cut into alternating hard and soft rock layers with an essentially horizontal attitude. Their profiles are stair-stepped and angular, they commonly have summits of variable width, and are bounded both above and below, by hills or escarpments.

Subsoil. Technically, the B horizon; roughly, the part of the solum below plow depth.

Substratum. The part of the soil below the solum.

Subsurface layer. Any surface soil horizon (A, E, AB, or EB) below the surface layer.

Summit. A general term for the top, or highest area of a landform such as a butte, hill, mountain, structural bench, mesa, or plateau. Summits may or may not include distinct crest lines or high points that rise above their general level.

Surface layer. The soil ordinarily moved in tillage, or its equivalent in uncultivated soil, ranging in depth from about 4 to 10 inches (10 to 25 centimeters). Frequently designated as the "plow layer," or the "Ap horizon."

Surface soil. The A, E, AB, and EB horizons. It includes all subdivisions of these horizons.

Taxadjuncts. Soils that cannot be classified in a series recognized in the classification system. Such soils are named for a series they strongly resemble and are designated as taxadjuncts to that series because they differ in ways too small to be of consequence in interpreting their use and behavior.

Tertiary. The first period of the Cenozoic Era of geologic time (from approximately 65 to 2 million years ago).

Terrace. An embankment, or ridge, constructed across sloping soils on the contour or at a slight angle to the contour. The terrace intercepts surface runoff so that water soaks into the soil or flows slowly to a prepared outlet.

Terrace (geologic). An old alluvial plain, ordinarily flat or undulating, bordering a river, a lake, or the sea.

Texture, soil. The relative proportions of sand, silt, and clay particles in a mass of soil. The basic textural classes, in order of increasing proportion of fine particles, are sand, loamy sand, sandy loam, loam, silt loam, silt, sandy clay loam, clay loam, silty clay loam, sandy clay, silty clay, and clay. The sandy soil materials consist of sands (coarse sand, sand, fine sand, very fine sand), loamy sands (loamy coarse sands, loamy sand, loamy fine sand, loamy very fine sand). Loamy soil materials consist of coarse sandy loam, sandy loam, fine sandy loam, very fine sandy loam, loam, silt loam, silt, clay loam, sandy clay loam, and silty clay loam. Clayey soil materials consist of sandy clay, silty clay, and clay.

Thin layer (in tables). Otherwise suitable soil material too thin for the specified use.

Toe slope. The outermost inclined surface at the base of a hill; part of a foot slope.

Too arid (in tables). The soil is dry most of the time, and vegetation is difficult to establish.

Topsoil. The upper part of the soil, which is the most favorable material for plant growth. It is ordinarily rich in organic matter and is used to topdress roadbanks, lawns, and land affected by mining.

Trace elements. Chemical elements, for example, zinc, cobalt, manganese, copper, and iron, are in soils in extremely small amounts. They are essential to plant growth.

Triassic. The first period of the Mesozoic Era of geologic time (from approximately 230 to 195 million years ago).

Tuff. A compacted deposit that is 50 percent or more volcanic ash and dust.

Upland (geology). Land at a higher elevation, in general, than the alluvial plain or stream terrace; land above the lowlands along streams.

Variegation. Refers to patterns of contrasting colors assumed to be inherited from the parent material rather than to be the result of poor drainage.

Weathering. All physical and chemical changes produced in rocks or other deposits at or near the earth's surface by atmospheric agents. These changes result in disintegration and decomposition of the material.

Well graded. Refers to soil material consisting of coarse grained particles that are well distributed over a wide range in size or diameter. Such soil normally can be easily increased in density and bearing properties by compaction. Contrasts with poorly graded soil.

HUALAPAI TRIBAL COUNCIL
RESOLUTION NO. 67-97
OF THE GOVERNING BODY OF THE
HUALAPAI TRIBE OF THE HUALAPAI RESERVATION

(Sacred Canyon/Spring Sites on the Hualapai Reservation)

WHEREAS, the Constitution and Bylaws of the Hualapai Indian Tribe provide that the governing body of the Hualapai Indian Tribe is the Hualapai Tribal Council; and

WHEREAS, the Hualapai Tribal Council has the power and the authority to enact laws and ordinances to protect the land and resources of the Hualapai Tribe for the Hualapai people; and

WHEREAS, the Hualapai Tribal Council has the responsibility to preserve the sanctity of the Tribe's natural and cultural resources including our sacred grounds, archaeological sites and ceremonial areas; and

WHEREAS, the Hualapai Indian Tribe adopted a conservation ordinance No. 24-70, amended in 1990 which prohibits entry into the Tribes' sacred canyons unless such entry is done in accordance with the conservation code; and

WHEREAS, the great seal of the Hualapai Tribe reflects the importance the Hualapai Indian Nation places on the canyons when it states "the Canyons are represented by the purples in the middle ground, where the people were created. These canyons are Sacred, and should be so treated at all times"; and

WHEREAS, certain canyons and springs because of their location and relationship with the universe, legends and creation have a greater importance to the Hualapai Tribe than others; and

WHEREAS, the Hualapai Tribe has set aside an area known as Grand Canyon West for economic development purposes; and

WHEREAS, the reason for setting aside Grand Canyon West was to preserve the rest of the Hualapai Indian Reservation from economic development without the proper approval from the Tribal Council and concurrence of the tribal elders in order to protect sacred tribal lands.

NOW, THEREFORE, BE IT RESOLVED that the Hualapai Tribal Council announces its intent to protect the sacred canyons consisting of Madwida Canyon, Spencer Canyon, National Canyon, Horse Flats Canyon, Diamond Creek, Travertine Canyon, Bridge Canyon, Hindu Canyon, Granite Park Canyon, Mohawk Canyon, Propspect Canyon, Jackson Canyon, Honga Springs, Valcon's Anvil Hell's Hollow, Beecher Springs, Three Springs Canyon, Separation Canyon, Clay Tank Canyon, Quartermaster Canyon, Cave Canyon, Travertine Falls, Milkweed Springs, Pumpkin Springs, Medicine Springs, Indian Springs, Whitmore Wash and Pierce Ferry, because of the location of sacred sites, ceremonial sites and archaeological sites within these canyons and springs;

BE IT FURTHER RESOLVED that the Chairman is authorized to inform the National Park Service and the Federal Aviation Administration of the sacred nature of these canyons and request that no air tours be allowed to fly over these canyons; and

BE IT FINALLY RESOLVED, that the Chairman is authorized to take any and all steps necessary to implement this resolution.

C E R T I F I C A T I O N

I, the undersigned as Chairman of the Hualapai Tribal Council hereby certify that the Hualapai Tribal Council of the Hualapai Tribe is composed of nine (9) members of whom _7_ consituting a quorum were present at a **SPECIAL COUNCIL MEETING** thereof held on this **22nd day of October, 1997**; and that the foregoing resolution was duly adopted by a vote of _7_ in favor, _0_ opposed , _0_ not voting, _2_ excused pursuant to authority of Article V, Section (a) of the Constitution of the Hualapai Tribe approved March 13, 1991.

Earl Havatone

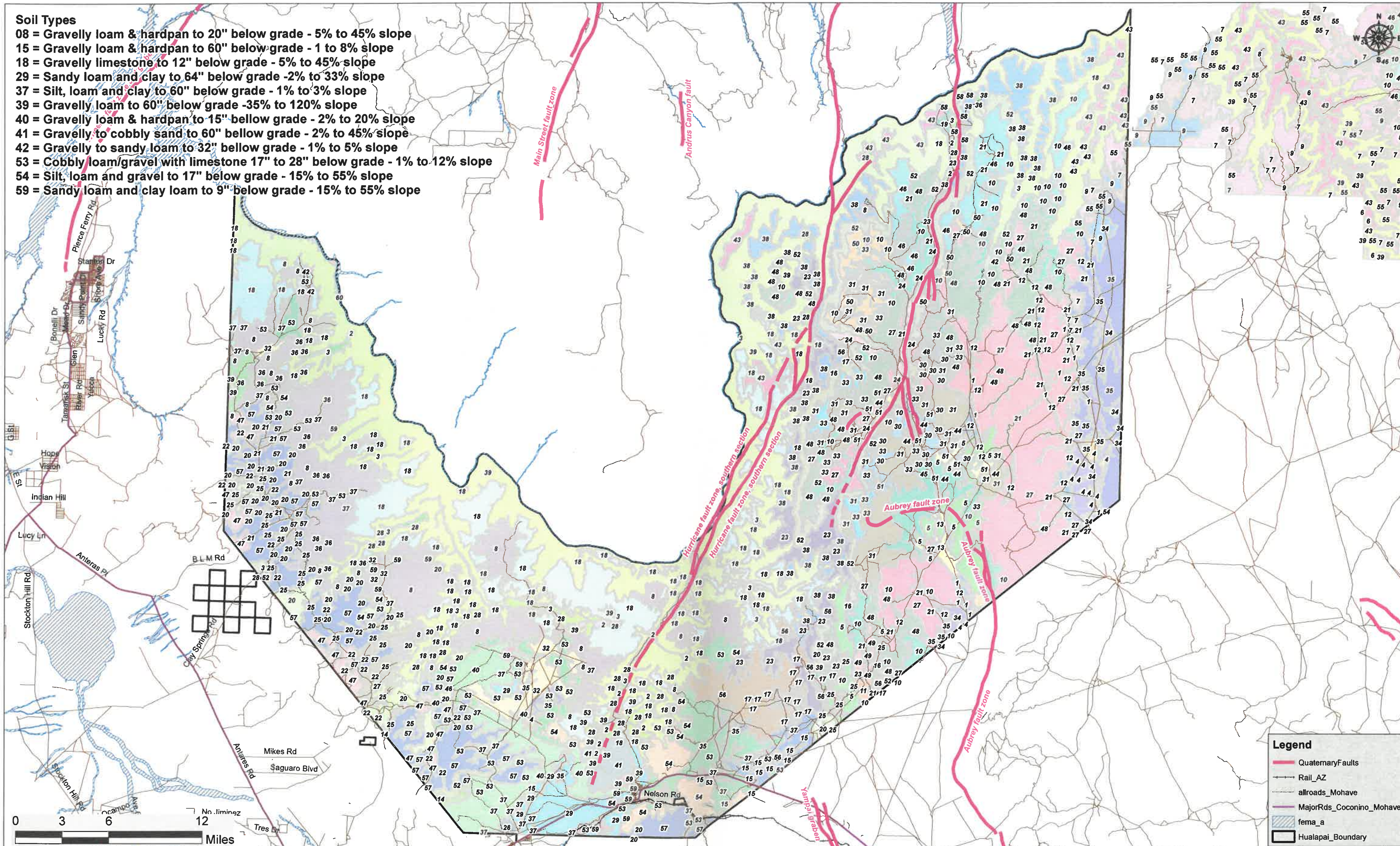
Earl Havatone, Chairman
Hualapai Tribal Council

ATTEST:

Christine Lee

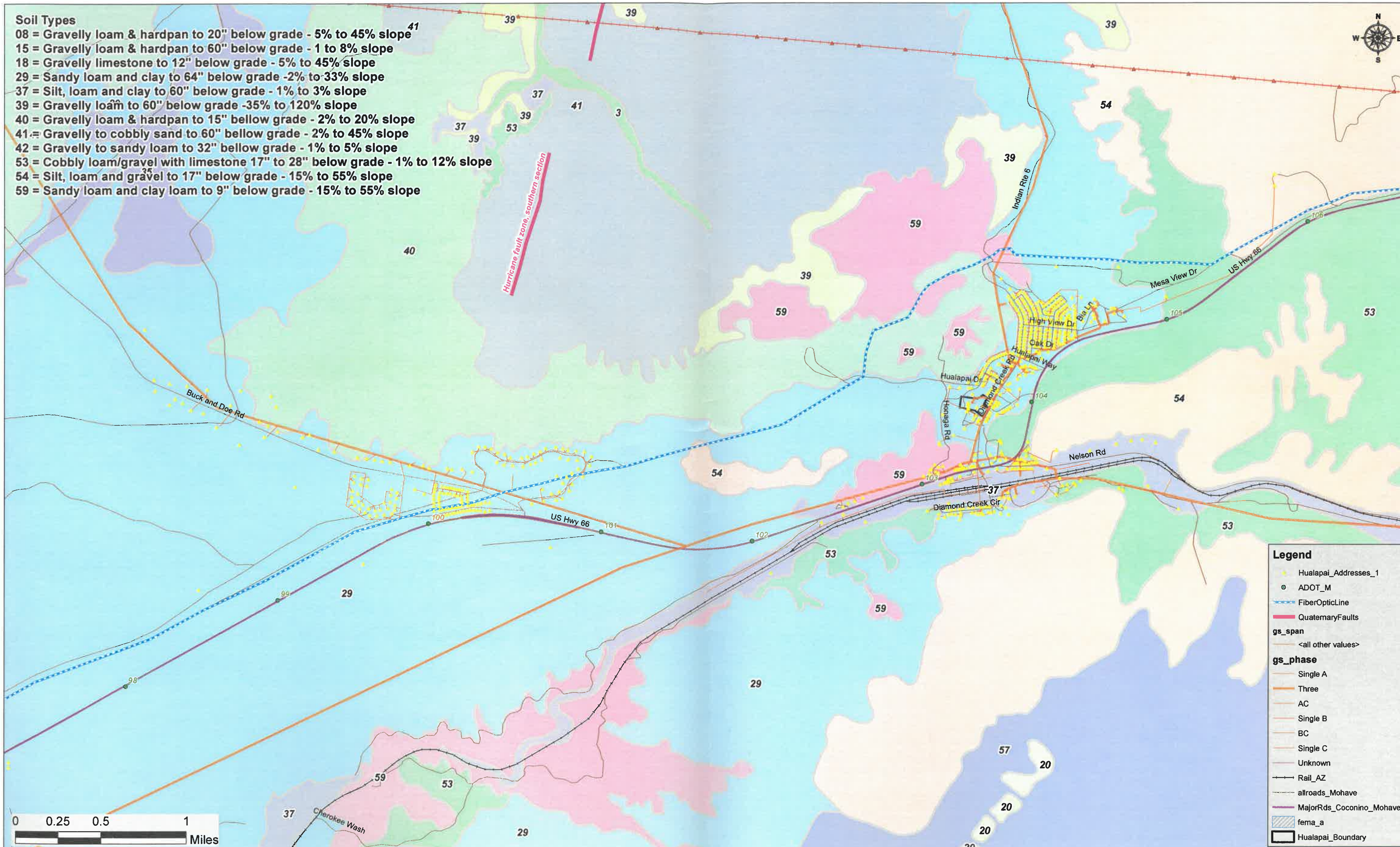
Christine Lee, Secretary
Hualapai Tribal Council

Fault Zones overlain on NRCS Soil Types



Drawn by: Kevin Davidson, 1/17/2023

Fault Zones overlain on NRCS Soil Types in Peach Springs and Buck & Doe Communities



Drawn by: Kevin Davidson, 1/17/2023

Earthquake Hazard Maps

https://www.fema.gov/emergency-managers/risk-management/earthquake/hazard-maps

The colors in the maps denote "seismic design categories" (SDCs), which reflect the likelihood of experiencing earthquake shaking of various intensities. (Building design and construction professionals use SDCs specified in building codes to determine the level of seismic resistance required for new buildings.)

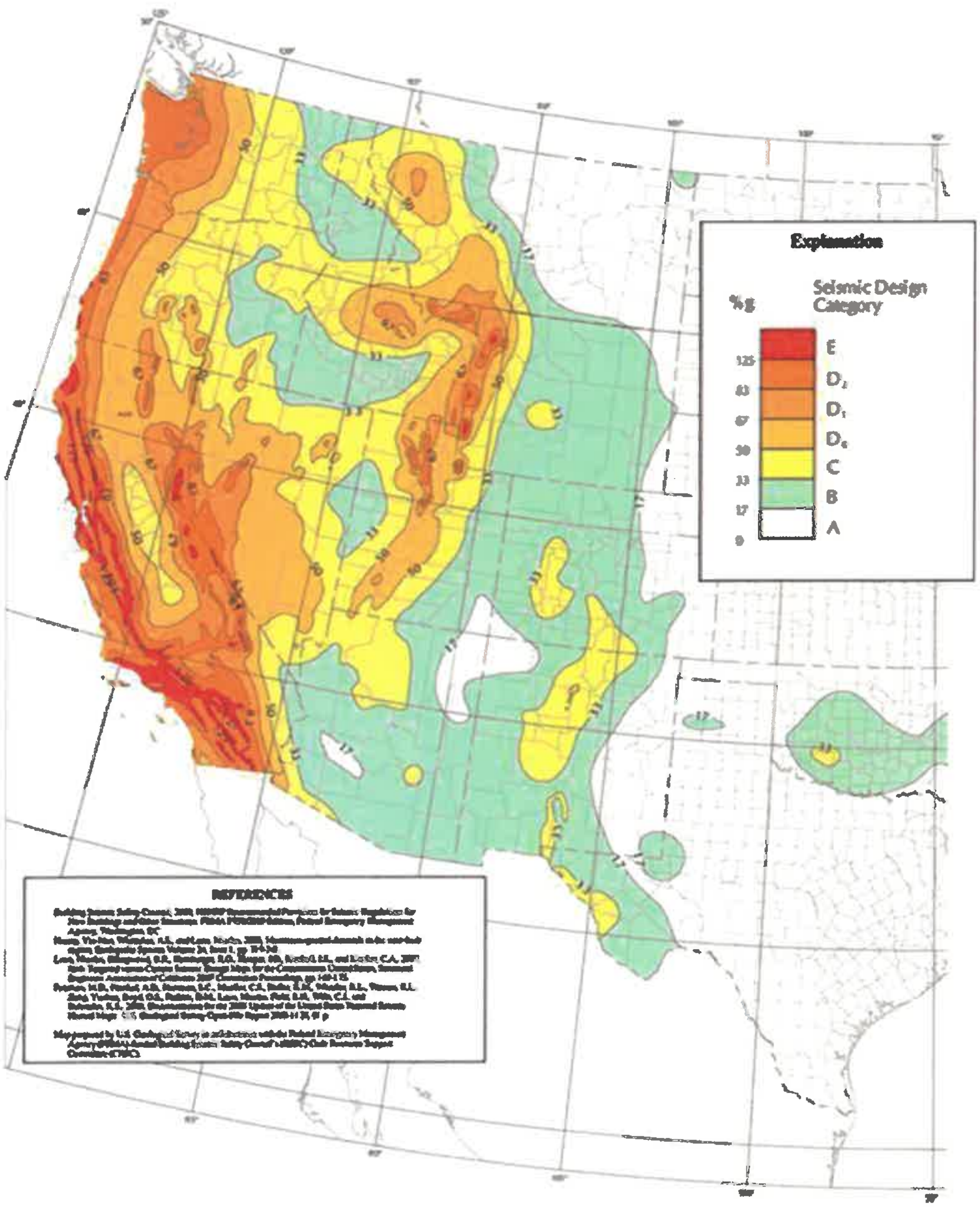
The following table describes the hazard level associated with each SDC and the associated levels of shaking. Although stronger shaking is possible in each SDC, it is less probable than the shaking described.

SDC/Map Color	Earthquake Hazard	Potential Effects of Shaking
A/White	Very small probability of experiencing damaging earthquake effects.	
B/Gray	Could experience shaking of moderate intensity.	Moderate shaking—Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
C/Yellow	Could experience strong shaking.	Strong shaking—Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built structures.
D/Light Brown D1/Darker Brown D2/Darkest Brown	Could experience very strong shaking (the darker the color, the stronger the shaking).	Very strong shaking—Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures.
E/Red	Near major active faults capable of producing the most intense shaking.	Strongest shaking—Damage considerable in specially designed structures; frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations. Shaking intense enough to completely destroy buildings.

*Abbreviated descriptions from The Modified Mercalli Intensity (MMI) Scale.

SDCs take into account the type of soil at the site, as poor soils can significantly increase earthquake shaking. These maps have simplified this by assuming normal Site Class “D” soils, which are the most commonly found.

When viewing the maps, it is important to remember that areas with high earthquake hazards do not necessarily face high seismic risks. Defined as the losses that are likely to result from exposure to earthquake hazards, seismic risks are determined not only by hazard levels but also by the amount of people and property that are exposed to the hazards and by how vulnerable people and property are to the hazards.



Hualapai Nation Soil & Water Conservation District

Hualapai Seven Generation Plan

-Know areas of reservation better to understand the land and how to care for it and gain resources from it.

-Teaching youth and all age groups about cultural areas and natural foods available.

-Going into schools to introduce agriculture, ranching, wildlife, gardening, and how to utilize the land.

-Coexistence between cattle and wildlife, teaching animal husbandry to hunters and ranchers.

-Range management, overgrazing, teach the youth about these things.

-Teach discipline and work ethics to the youth.

-Work with families.

-Forest products from reservation, start a business which would create jobs.

-Clean up litter and stop illegal dumping.

-Water conservation; water rights of Tribe.

-Educational workshops for the youth to introduce agriculture.

-Taking youth on field trips out onto reservations so they can see the natural resources available and appreciate them.

-Soil erosion, working on areas where there's soil erosion.

-Higher quality of housing.

-Invasive species of plants; removal of and bring back native plants.

-Recycling; educating tribal members about recycling.

-Cleaning up dump sites.

-Cleaning up natural springs.

-Community Kitchen

-Have the youth active in areas of natural resources.

-Better quality of water on the reservation.

-Reseeding overgrazed areas.

-Better communication and educating Tribal members and youth about natural resources, history, and culture.

How do we want range lands to be in the next seven generations?

1. Excellent
2. Good
3. Fair
4. Poor

(Excellent & Good)

How about Forest Lands? (Excellent & Good)

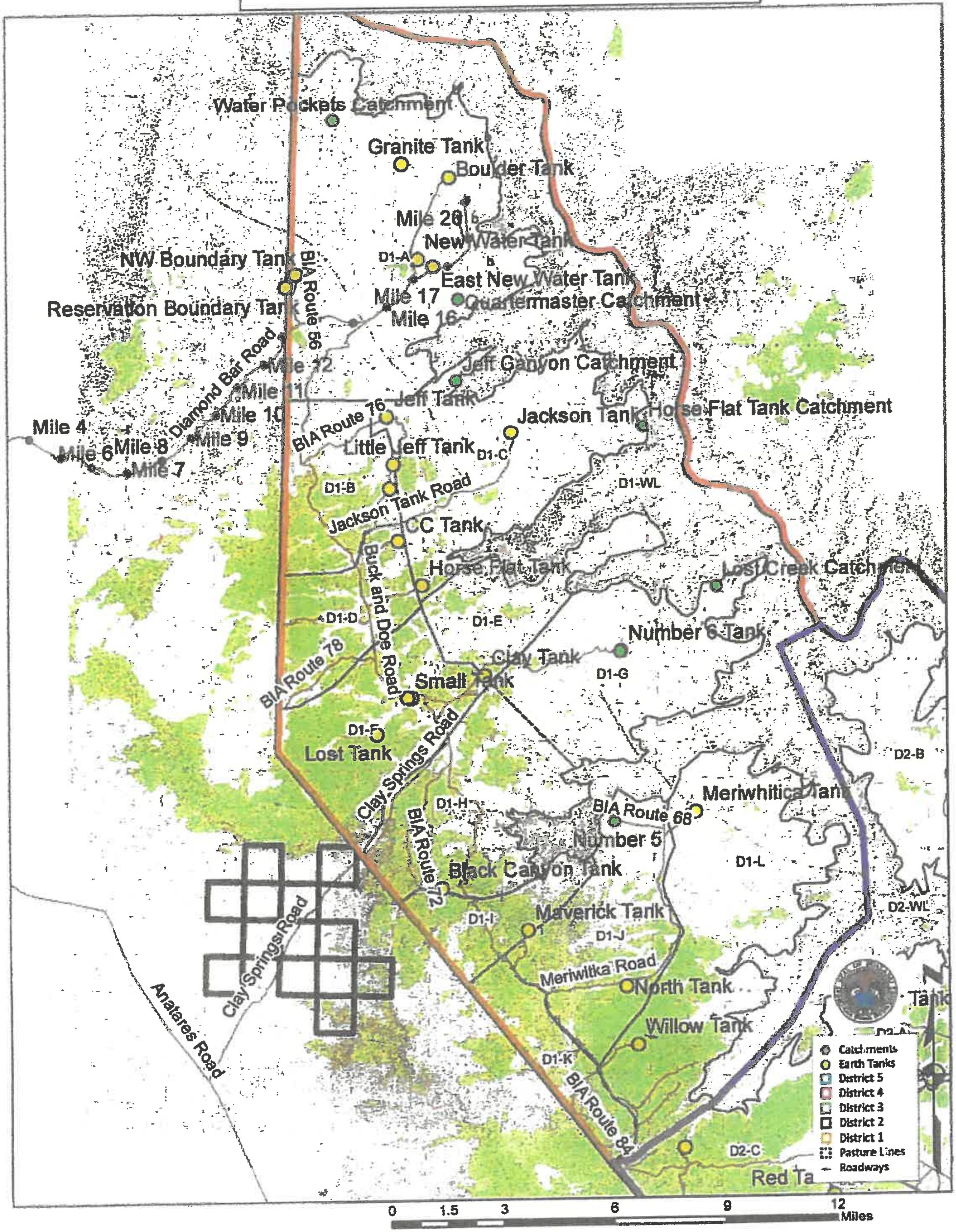
-Using Forest Resources; rough cut lumber for fencing.

In Seven Generations:

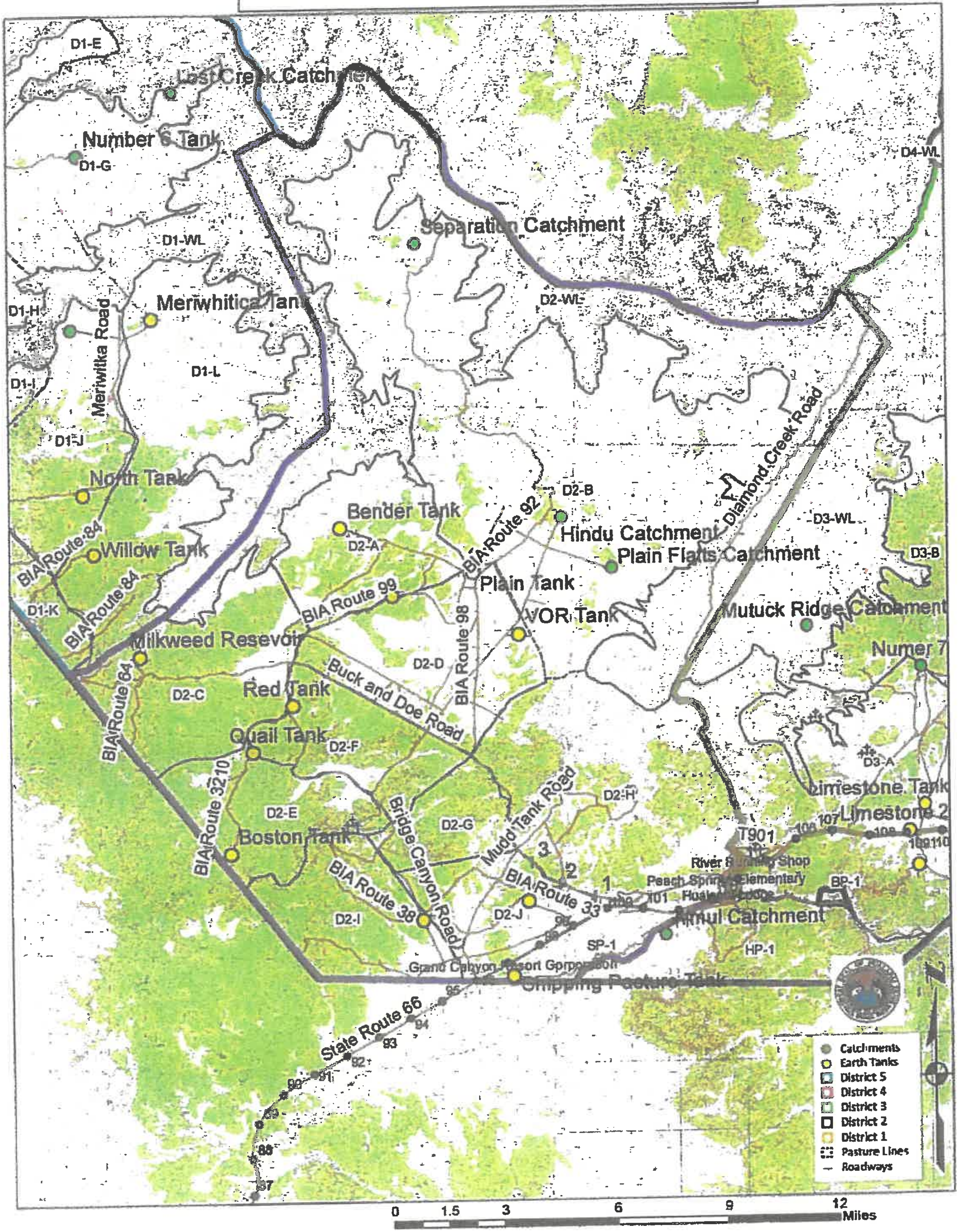
1. Have diabetes eradicated on reservation.
2. Unemployment
   a. Work Ethic
   b. Self Sufficiency
3. High School Dropout Rate:
   a. 100% no dropout rate
4. Higher than national average college degrees among Native Americans.
   a. Adequate number of tribal youth entering Natural Resource Fields.
   b. Adequate number of tribal youth entering into Ranching & Farming.
   c. Tier of ages practicing Ranching & Farming.
5. Developing an education plan for the youth:
   a. Natural Resources
   b. Agriculture
   c. Tribal Culture and Arts & Crafts
   d. Outdoor Classrooms
6. Littering and illegal dumping will cease to be a problem.
7. Invasive species of plants eliminated or controlled.
8. Storehouse of produce grown by Tribal members.
9. Local Processing Facilities:
   a. Farmers Markets
   b. Community & Family Gardens
   c. Schools & Tribal facilities utilizing locally grown food produce.
10. Adequate supply of culturally significant plants.
11. Rangelands are in good and excellent condition.
    a. Coexistence of wildlife and livestock, how?
12. Quality of Housing
    a. Housing to fit in with environment
13. Water
14. Utilizing land to grow various crops.
15. Self sufficiency of Tribe:
    a. Businesses being owned and operated by tribal members.
16. Alternative Energy
    a. Solar
    b. Wind
    c. Water
    d. Woody Bio-mass

17. Industry and Manufacturing:
    a. Portable Sawmill
    b. Creating job opportunities
18. Reduction of alcohol and drug related activities.

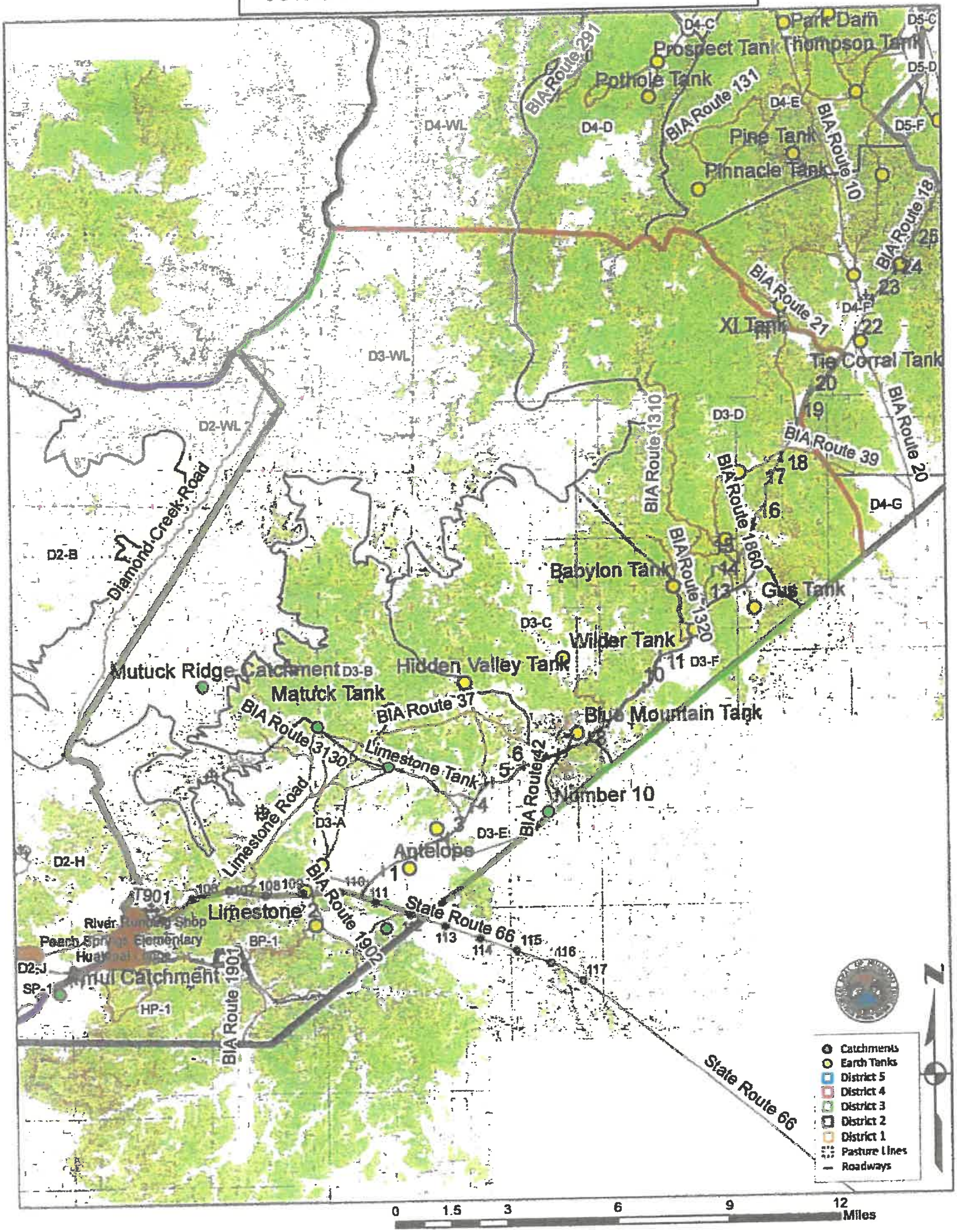
Hualapai Reservation
Cattle Districts and Pastures - District 1



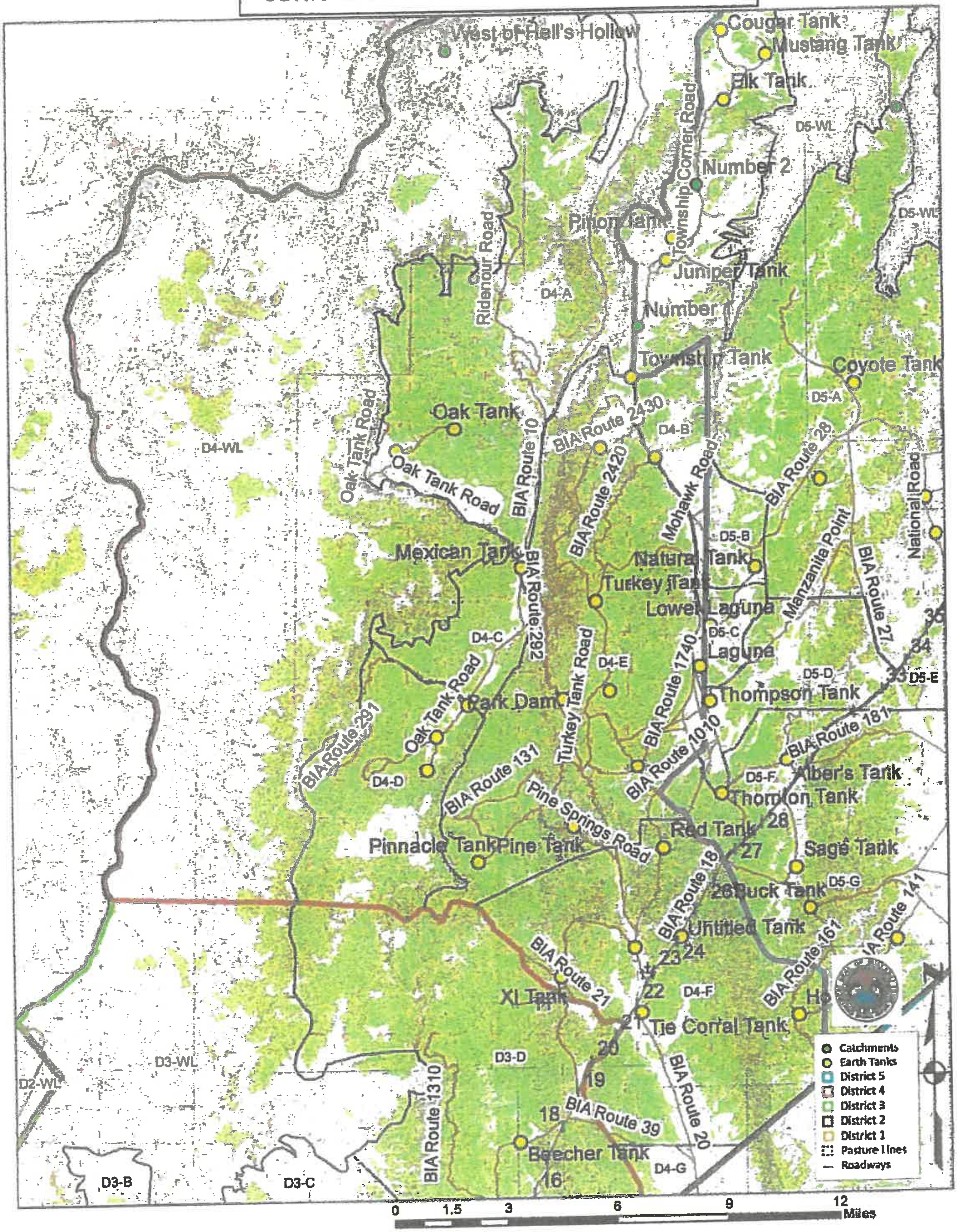
Hualapai Reservation
Cattle Districts and Pastures - District 2



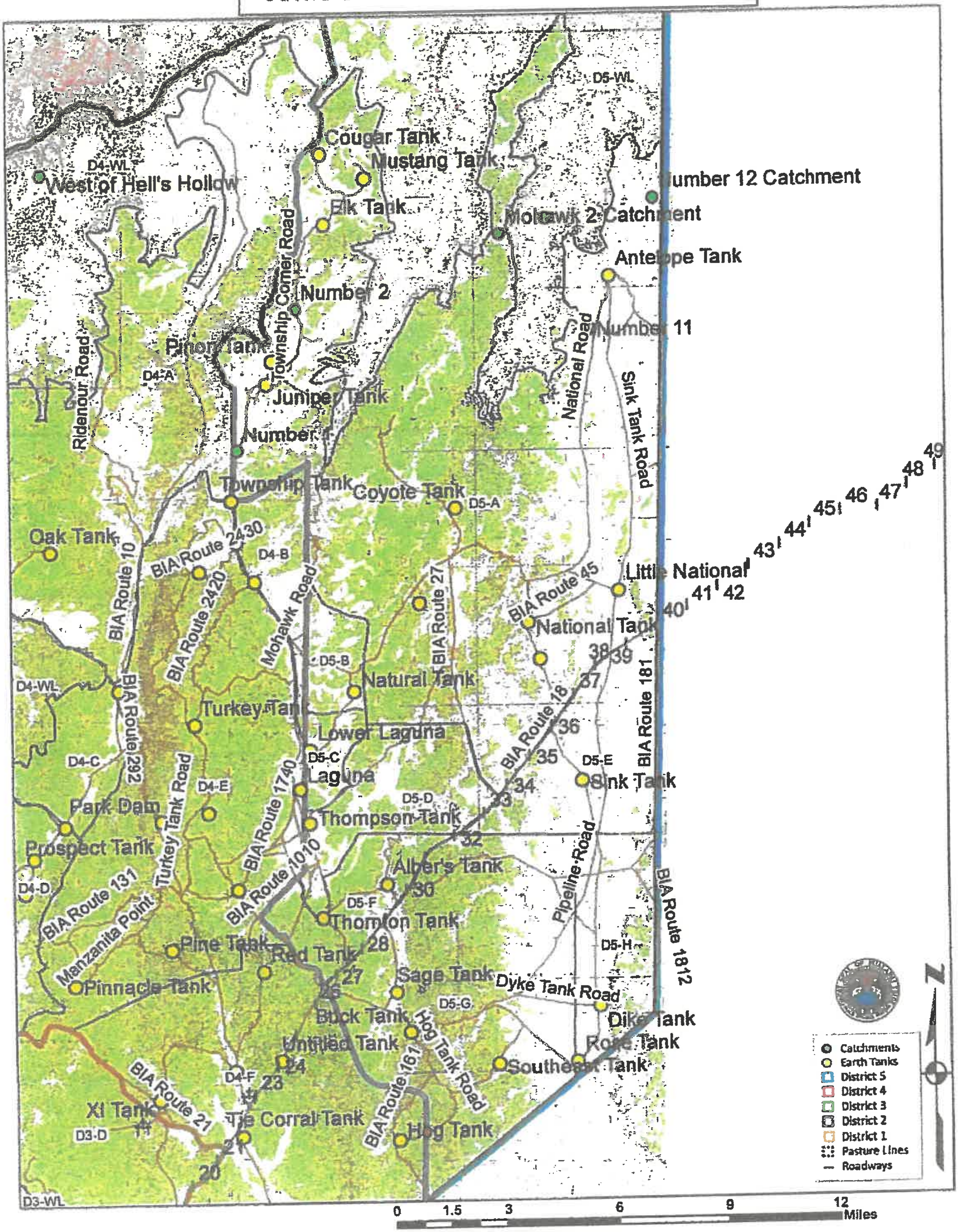
Hualapai Reservation
Cattle Districts and Pastures - District 3



Hualapai Reservation
Cattle Districts and Pastures - District 4



Hualapai Reservation
Cattle Districts and Pastures - District 5



The Christian Science Monitor

Henry Nicholls/Reuters
A man holds up a flag as climate activists from Extinction Rebellion take part in a demonstration at Oxford Circus in London April 9, 2022.

THE EXPLAINER

Official climate reports pile up. But do they connect with the public?

- QUICK READ

- By Stephanie Hanes Staff writer @stephaniehanes

May 10, 2022

In early April, more than a thousand scientists around the world decided to protest. They chained themselves to government buildings, blocked intersections, and staged sit-ins. In Spain, they threw fake blood on the facade of the parliament building. In Los Angeles, police arrested a lab-coated crew who had attached themselves to a JPMorgan Chase building to oppose the financing of fossil fuels.

"The scientists of the world have been being ignored," said NASA climate scientist Peter Kalmus, voice trembling, as he stood with the other Los Angeles protesters. "It's got to stop. We're going to lose everything. ... We're not lying; we're not exaggerating."

The impetus for these demonstrations was a new report from some 200 authors and a United Nations group called the Intergovernmental Panel on Climate Change (IPCC). For Dr. Kalmus and many others involved in climate research, the document screamed both warning and accusation – proof that governments, businesses, and individuals must immediately change course to avoid increasingly catastrophic impacts of climate change. It also gave road maps for avoiding worst-case scenarios – if people will follow them.

WHY WE WROTE THIS

In a regular drumbeat, international experts summarize the global state of climate science. But the exhaustive detail can overwhelm. We look at what the efforts to distill a scientific consensus really mean.

But what's clear to the scientists isn't always straightforward to everyone else.

In a study last year, researchers found that most Americans are confused by terms traditionally used to convey climate information, such as "tipping point" or "mitigation." Add the acronym-heavy international climate world, with its multiple working groups, assessments, and "COPs" that have nothing to do with policing, and it's easy to understand why the public's reaction to these reports can differ from the scientists'.

"I don't think people necessarily get how the IPCC works," says Jacquelyn Gill, a paleoecologist and climate communications expert at the University of Maine. "Acronyms, scientific jargon, all of those things, they become a persistent bumper in scientific communications."

What is the IPCC and why does it matter?

The World Meteorological Organization and the U.N. Environment Program joined forces in 1988 to create the IPCC, an international body with the goal of reviewing the science, economic impact, and future threats of climate change. Since then, hundreds of scientists have volunteered every IPCC "assessment period," which lasts about seven years, to go over tens of thousands of published studies and distill their meaning.

"It's taking this mass of knowledge, taking all the experts involved, saying ... 'This is what we know; this is what policymakers need to know,'" says David McCollum, senior scientist at the Oak Ridge National Laboratory in Tennessee and an IPCC author.

This "big picture" process is both exhaustive and bureaucratic. The IPCC staff carefully picks scientists to represent different regions and disciplines. Expert reviewers and representatives from the world's governments look at what the scientists have written, and negotiate line by line in order to come to a consensus about the summary report.

This last step ensures that U.N. member countries have "buy-in" to the reports, explains Katherine Leitzell, a communications specialist who worked with the IPCC.

"The governments can't just come back and say no, that's nonsense."

Within the IPCC, three "working groups" of scientists tackle three big aspects of climate change: the physical science, such as how oceans are warming; who and what is vulnerable and how they might adapt; and mitigation, or ways to reduce greenhouse gas emissions.

This "trilogy" of IPCC work goes alongside another U.N. process, the Conference of the Parties, or COP, which focuses on policymaking.

The IPCC reports are supposed to help policymakers, businesses, municipalities, and even individuals make the most informed climate decisions possible.

What do the IPCC reports actually say?

Even though these reports are based on existing research, they still pack a message.

As Inger Andersen, executive director of the U.N. Environment Program, put it in a press conference last month, the first two reports in the IPCC's current cycle show that climate change is happening and is causing huge disruption to both the natural and human worlds. The third, most recent report shows that "we are still not doing enough to cut greenhouse gas emissions."

A quick pause here. "Greenhouse gas emissions" means the heat-trapping gases – such as carbon dioxide, methane, and nitrous oxide – that humans are releasing into the atmosphere alongside natural volumes of these gases. Carbon dioxide makes up the bulk of these, so that's why there's a lot of talk about "carbon footprints" or "decarbonization." Most of our carbon emissions come from burning fossil fuels. But we also release carbon dioxide in chemical processes, such as the one that makes cement, or by cutting down trees.

The past 20 years saw the highest increase in emissions in human history. And greenhouse gas concentrations in the
atmosphere are also at their highest levels in the history of humans on Earth, researchers say. That means that unless there are big, quick changes, it is all but inevitable that the impacts on human society and the natural world will get more severe.

"The jury has reached the verdict and it is damning," said U.N. Secretary-General António Guterres at a press conference in April. The new report "is a file of shame, cataloging the empty pledges that firmly put us on track towards an unlivable world. We are on a fast track to climate disaster."

Back up. Climate disaster?

Well, here's the thing about the concept of a climate disaster: Scientists know that with more warming come more negative impacts, and also the chance for natural cycles to reach "tipping points," or moments when normal natural processes unravel, potentially causing even more warming. But it's not so easy to describe what "disaster" means. Many people already are suffering catastrophic impacts of climate change, such as increased wildfires, deeper drought and crop failure, and extra-severe storms.

And what, actually, will happen in the future largely depends on one unknown variable: human behavior.

"The biggest uncertainty when it comes to our climate future is what we do," says Dr. Gill. "Not what the Earth is going to do."

So what can we do?

Humans – whether operating as governments, businesses, or individuals – can take steps to either limit warming or allow it to continue exponentially. And across society, we already have the tools to lower emissions. The most recent IPCC report explored how this could happen in various sectors, including transportation, agriculture, and energy, and also in different countries, with their unique economies, development statuses, and existing challenges.

"Scientists and governments know how to reduce emissions quickly," says Dr. McCollum, whose work with the IPCC focused on assessing models of future warming, under differing scenarios of human behavior. Achieving the most ambitious goals would require massive changes, he says, "but there are things we know how to do now."

This includes everything from speeding up the electrification of transportation systems (think electric cars and a robust charging station network), to making sure new construction meets stringent energy efficiency standards, to revamping financial systems to ensure adequate funding for experimental climate technology.

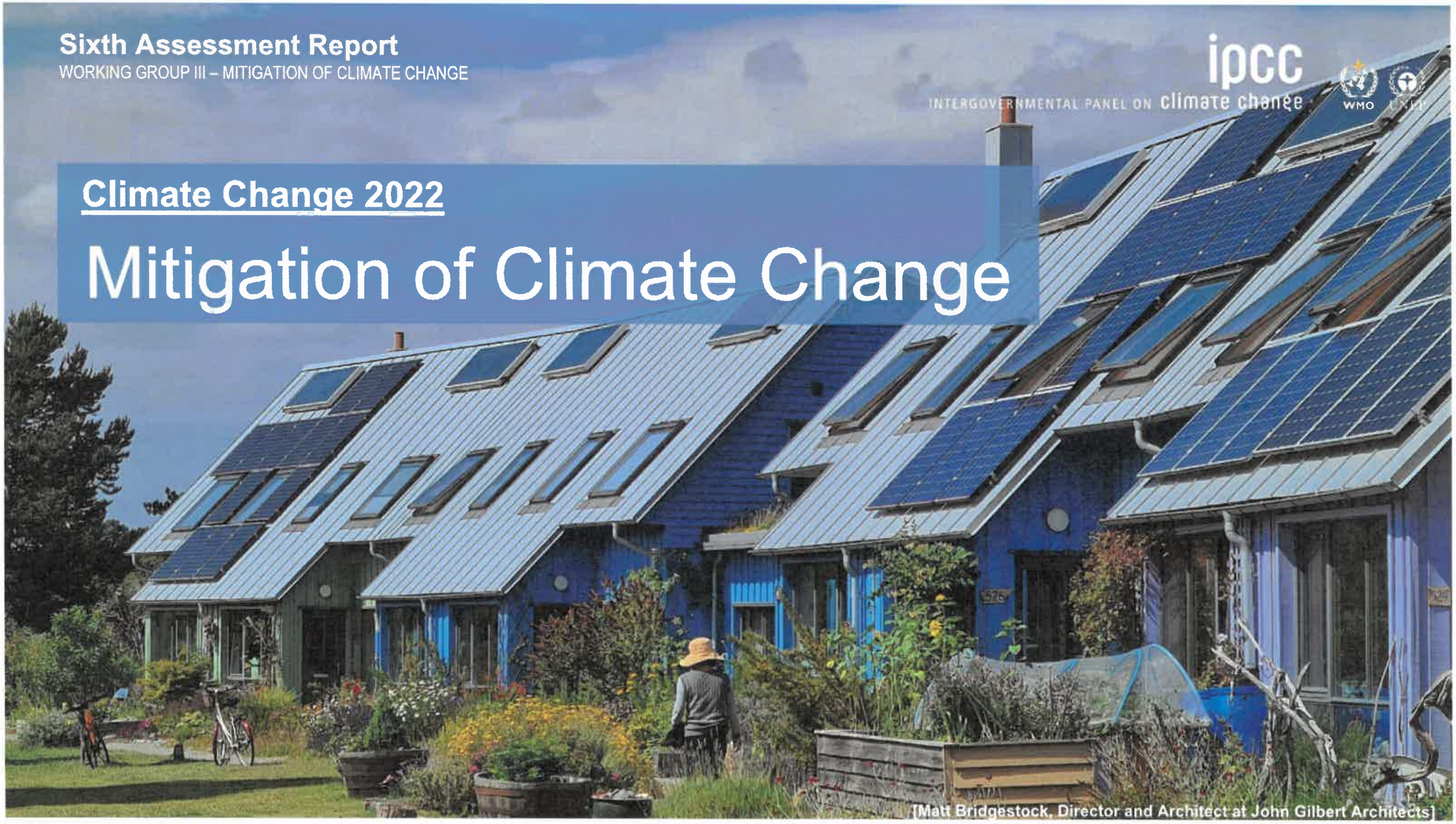
A rapid decrease of fossil fuel use is necessary to quickly lower emissions, the report's authors found. And the more we do, and quickly, is better.

But scientists caution against seeing climate change as a pass-fail situation, where if the world surpasses a certain warming level – 1.5 degrees Celsius is the one mentioned regularly – we've "lost."

"Every fraction of a degree is worth fighting for," says Dr. Gill. "And that will always be true."

Related stories

- Ice shelf collapse: 'Unknown' Antarctica still holds surprises
- In era of weather extremes, TV forecasters become climate educators
- Climate report: Hope is not lost, but 'we need to move faster'


Sixth Assessment Report
WORKING GROUP III – MITIGATION OF CLIMATE CHANGE
ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO
Climate Change 2022
Mitigation of Climate Change
[Matt Bridgestock, Director and Architect at John Gilbert Architects]

Report by numbers

278 Authors

65 Countries

41 % Developing countries
59 % Developed countries

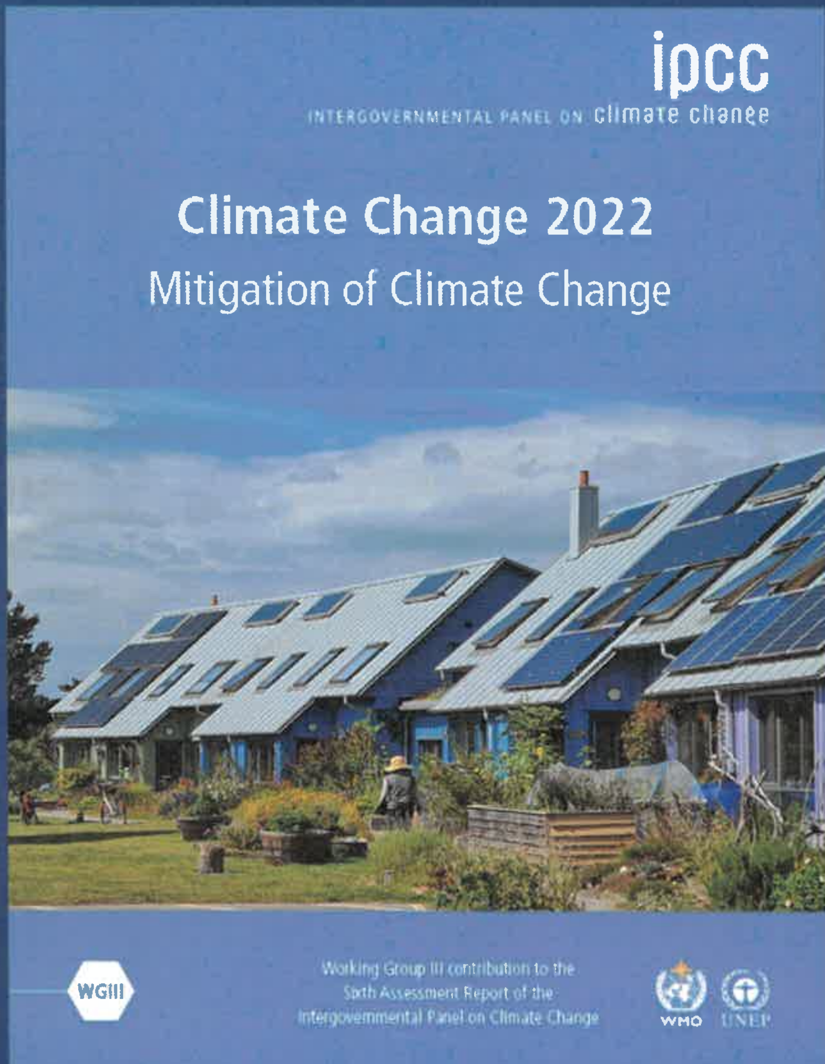
354 Contributing authors

29 % Women / 71 % Men

More than
18,000 scientific papers

59,212 Review comments

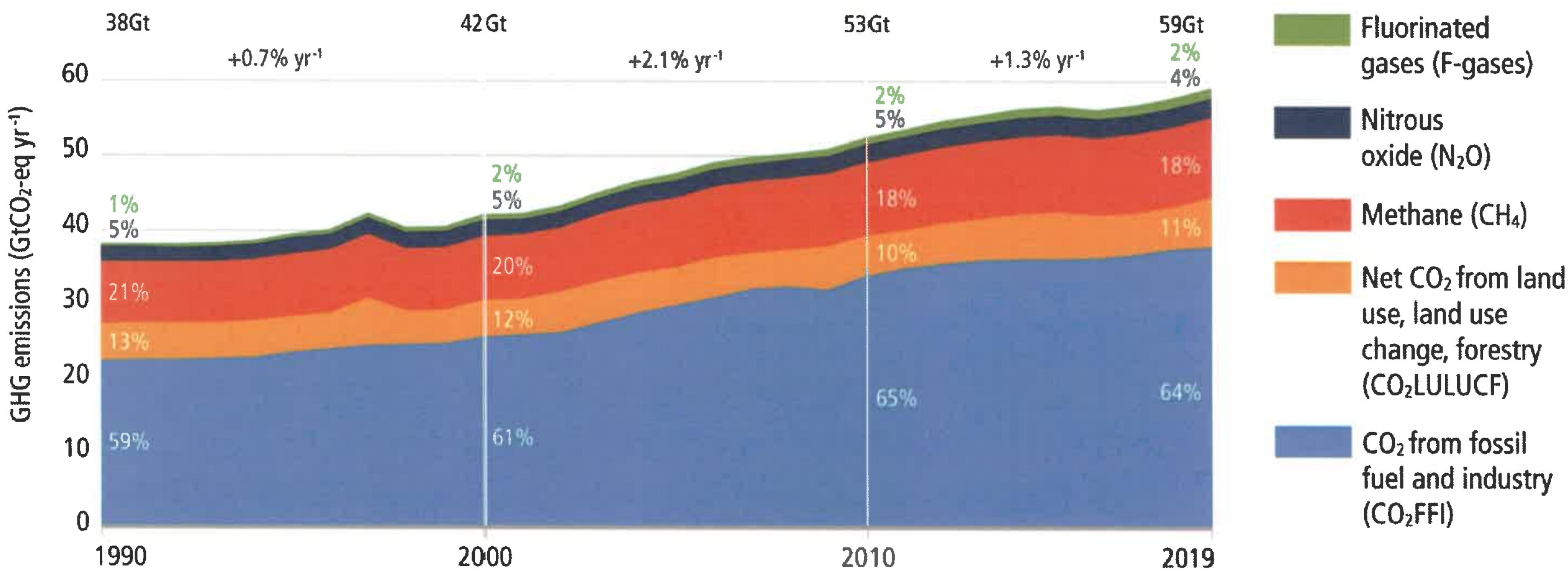
ipcc



[Matt Bridgestock, Director and Architect at John Gilbert Architects]

2010-2019: Average annual greenhouse gas emissions at highest levels in human history

We are not on track to limit warming to 1.5 °C.



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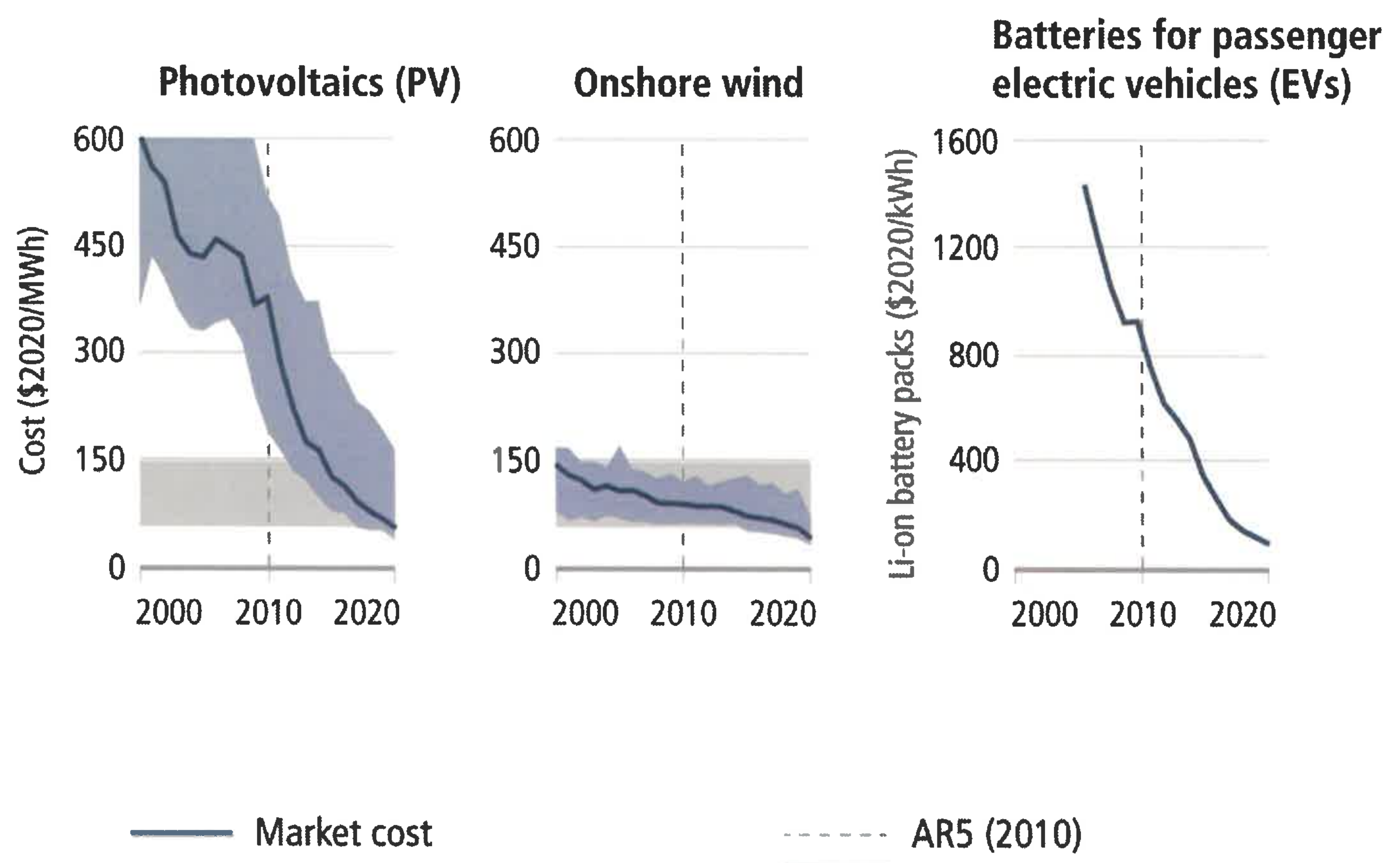
…but there is increased evidence of climate action
[Charlie Chesvick/IStock.com]

“Unless there are immediate and deep emissions reductions across all sectors, 1.5°C is beyond reach.

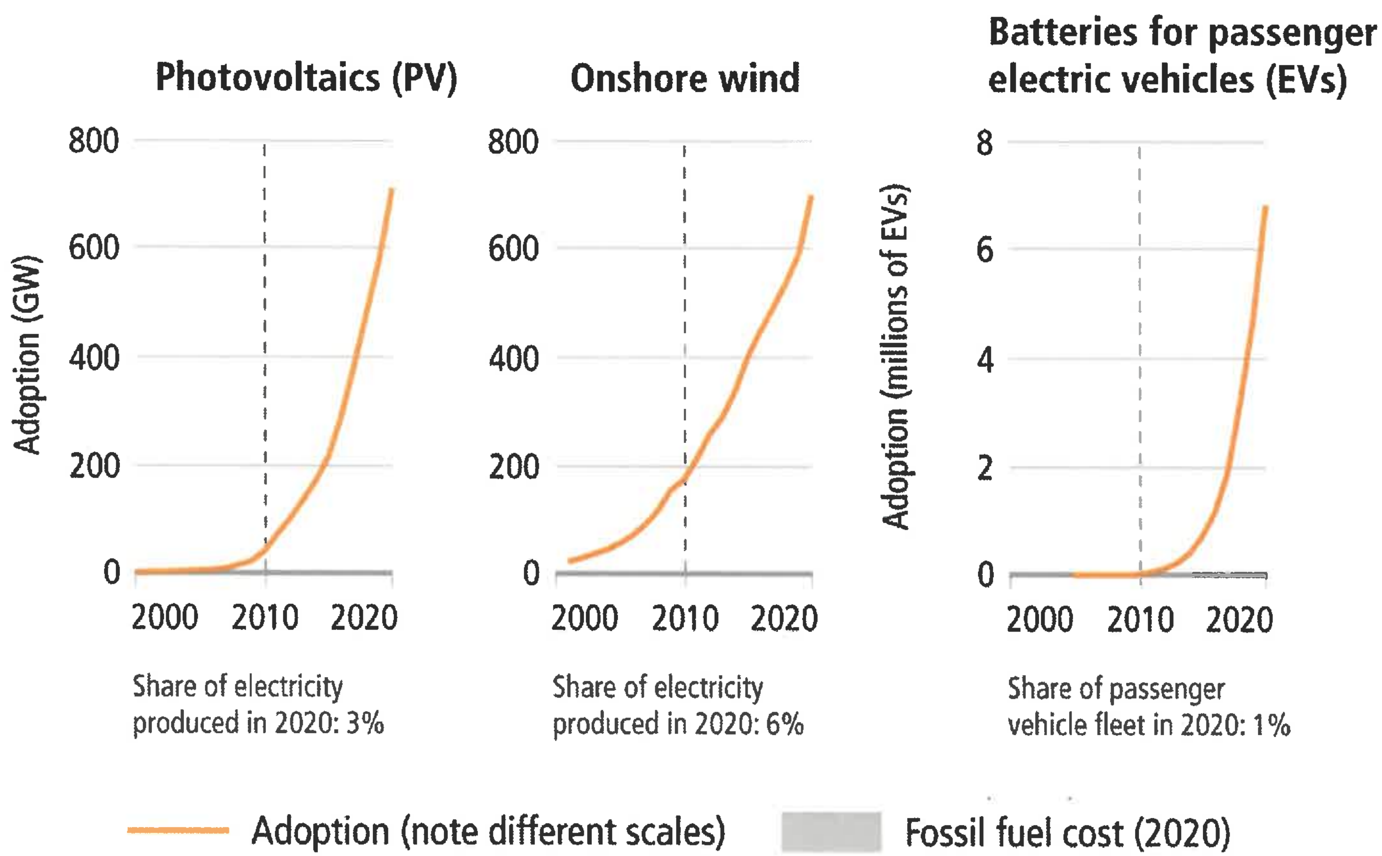
Increased evidence of climate action

Some countries have achieved a **steady decrease** in emissions **consistent** with limiting warming to **2°C.**

Zero emissions targets have been adopted by at least **826 cities and 103 regions**



In some cases, costs for renewables have fallen below those of fossil fuels.



Electricity systems in some countries and regions are already predominantly powered by renewables.

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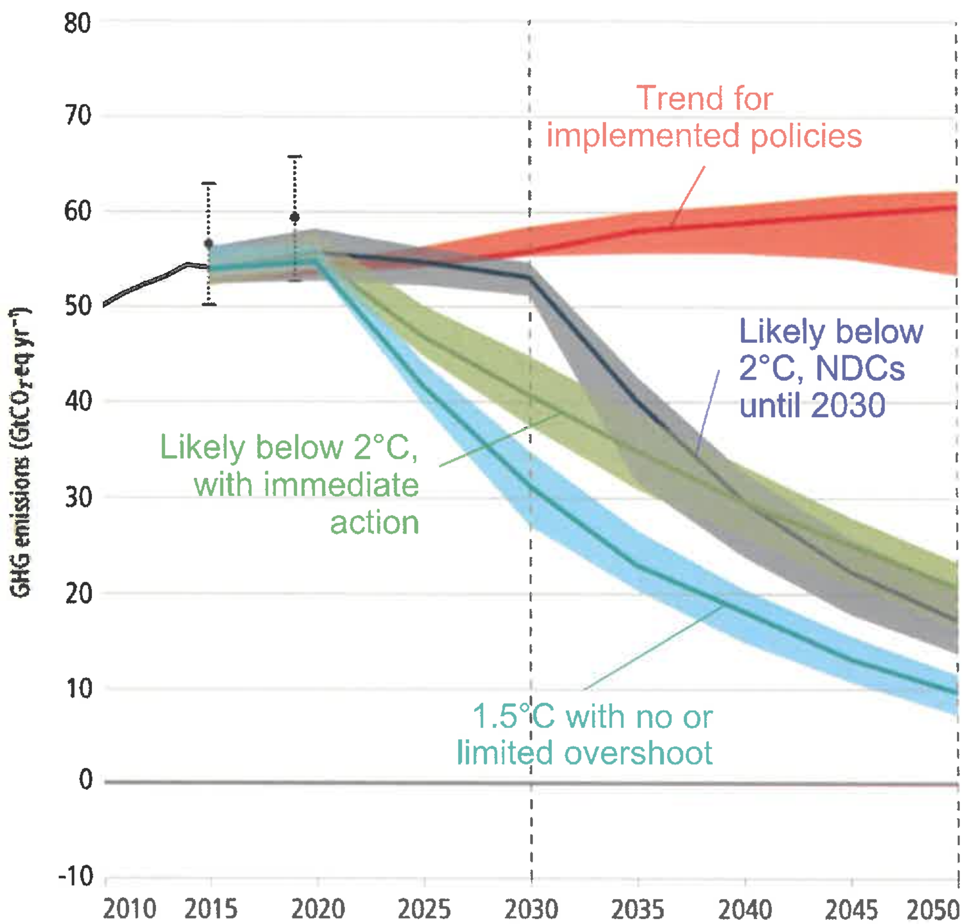
WORKING GROUP III – MITIGATION OF CLIMATE CHANGE



Limiting warming to 1.5 °C

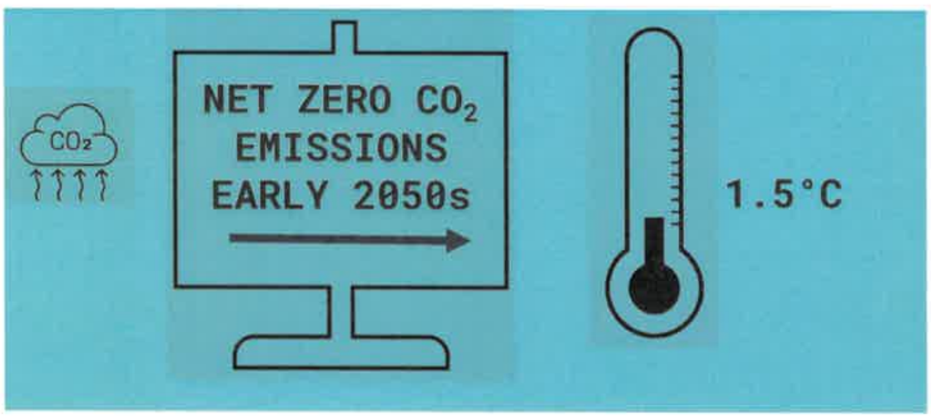
- Global GHG emissions peak before 2025, reduced by 43% by 2030.
- Methane reduced by 34% by 2030

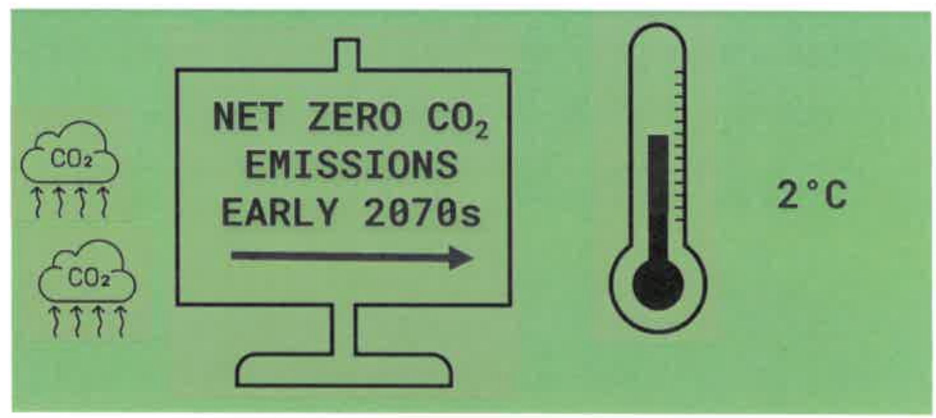
Limiting warming to around 2°C

- Global GHG emissions peak before 2025, reduced by 27% by 2030.

(based on IPCC-assessed scenarios)

The temperature will stabilise when we reach net zero carbon dioxide emissions





(based on IPCC-assessed scenarios)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INTERGOVERNMENTAL PANEL ON climate change
WMO
UNEP
There are options available **now** in every sector that can at least **halve** emissions by 2030
Demand and services
Energy
Land use
Industry
Urban
Buildings
Transport

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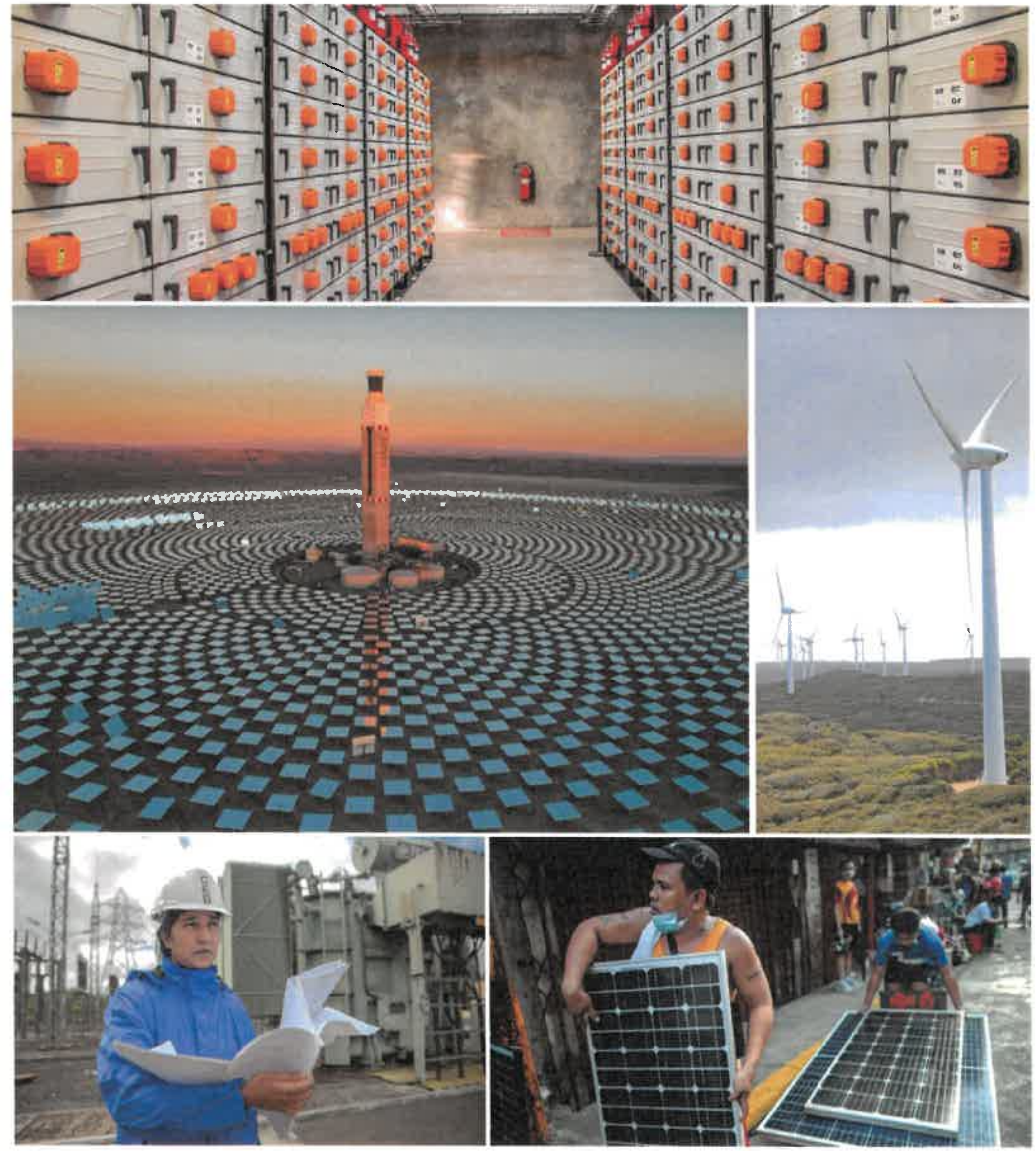
WORKING GROUP III – MITIGATION OF CLIMATE CHANGE

Energy

– **major transitions** are required to limit global warming
– reduction in fossil fuel use and use of carbon capture and storage
– low- or **no-carbon** energy systems
– widespread **electrification** and improved energy **efficiency**
– **alternative fuels**: e.g. hydrogen and sustainable biofuels



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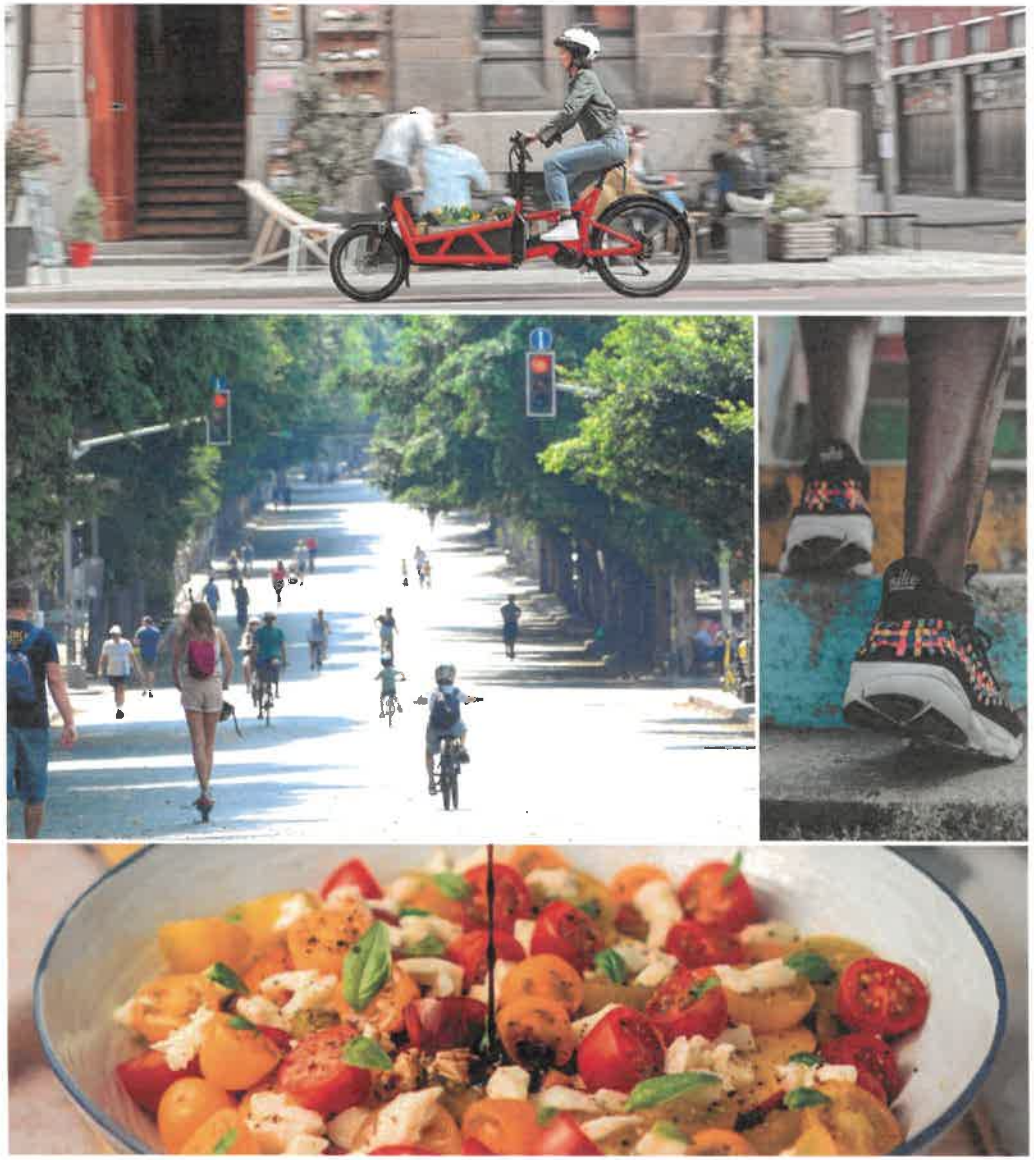


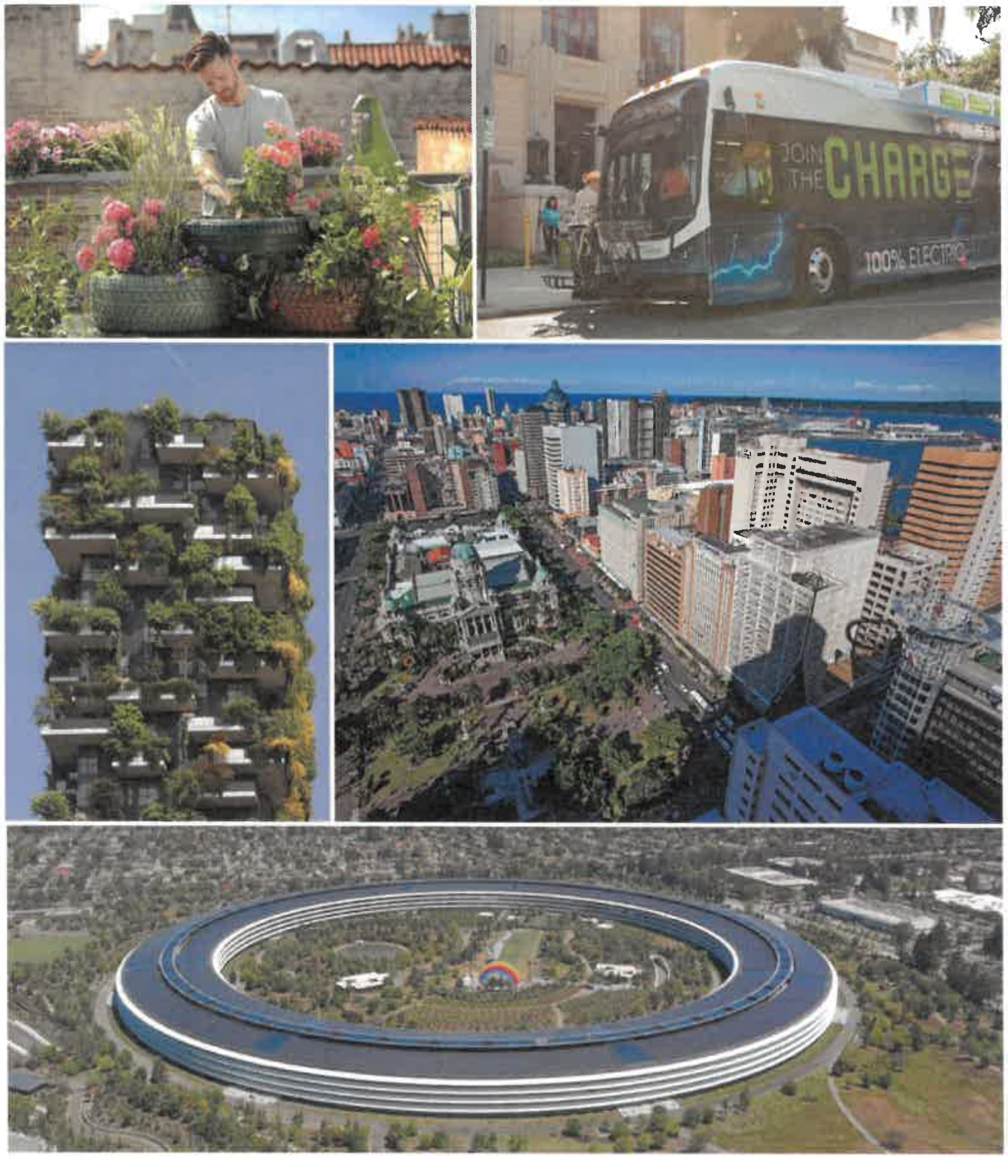
Demand and services

- potential to **bring down** global **emissions** by **40-70%** by 2050
- walking and cycling, electrified transport, reducing air travel, and adapting houses make large contributions
- **lifestyle changes** require **systemic changes** across all of society
- **some** people require additional **housing**, **energy** and **resources** for human wellbeing

[Bosch, Unsplash/Yoav Aziz, Adam Bartoszewicz, Victor Hernandez]

Transport

- **reducing demand** and **low-carbon** technologies are key to reducing emissions
- **electric vehicles**: greatest potential
- **battery technology**: advances could assist electric rail, trucks
- **aviation** and **shipping**: alternative fuels (low-emission **hydrogen** and **biofuels**) needed
- Overall, substantial potential but depends on **decarbonising the power sector**.



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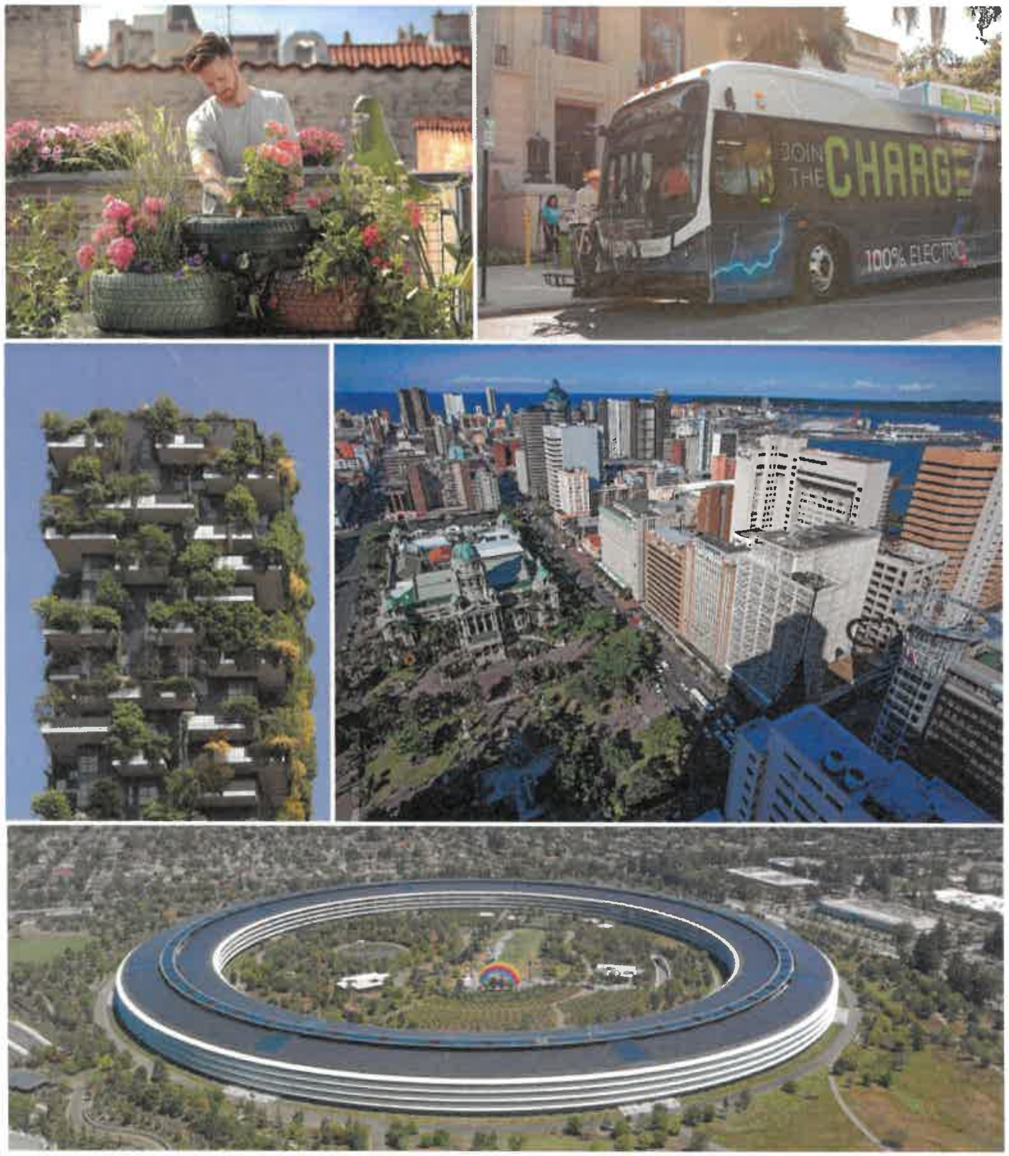
Cities and urban areas

- better urban planning, as well as:
- sustainable production and consumption of goods and services,
- **electrification** (low-emission energy),
- enhancing **carbon uptake and storage** (e.g. green spaces, ponds, trees)

There are options for existing, rapidly growing *and* new cities.



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Buildings

- buildings: possible to reach net zero emissions in 2050
- action in this decade is critical to fully capture this potential
- involves retrofitting existing buildings and effective mitigation techniques in new buildings
- requires ambitious policy packages
- zero energy and **zero-carbon** buildings exist in new builds **and retrofits**

Industry

- using materials more **efficiently**, **reusing**, **recycling**, **minimising waste**; currently **under-used** in policies and practice
- **basic materials**: low- to zero-greenhouse gas production processes at **pilot** to **near-commercial** stage
- achieving **net zero** is challenging

Sixth Assessment Report

WORKING GROUP III – MITIGATION OF CLIMATE CHANGE

Carbon Dioxide Removal

- required to **counterbalance hard-to-eliminate** emissions
- through **biological** methods: reforestation, and soil carbon sequestration
- **new technologies** require more **research**, up-front **investment**, and proof of concept at **larger scales**
- **essential** to **achieve net zero**
- **agreed methods** for measuring, reporting and verification required

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Land use

- can provide large-scale emissions reductions **and** remove and store CO_2 at scale
- protecting and restoring **natural ecosystems** to remove carbon: forests, peatlands, coastal wetlands, savannas and grasslands
- competing demands have to be **carefully managed**
- **cannot compensate** for **delayed** emission **reductions** in other sectors

Closing investment gaps

- financial flows: **3-6x lower** than levels needed **by 2030** to limit warming to below 1.5°C or 2°C
- there is **sufficient global capital** and liquidity to close investment gaps
- challenge of closing gaps is widest for developing countries

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Policies, regulatory and economic instruments

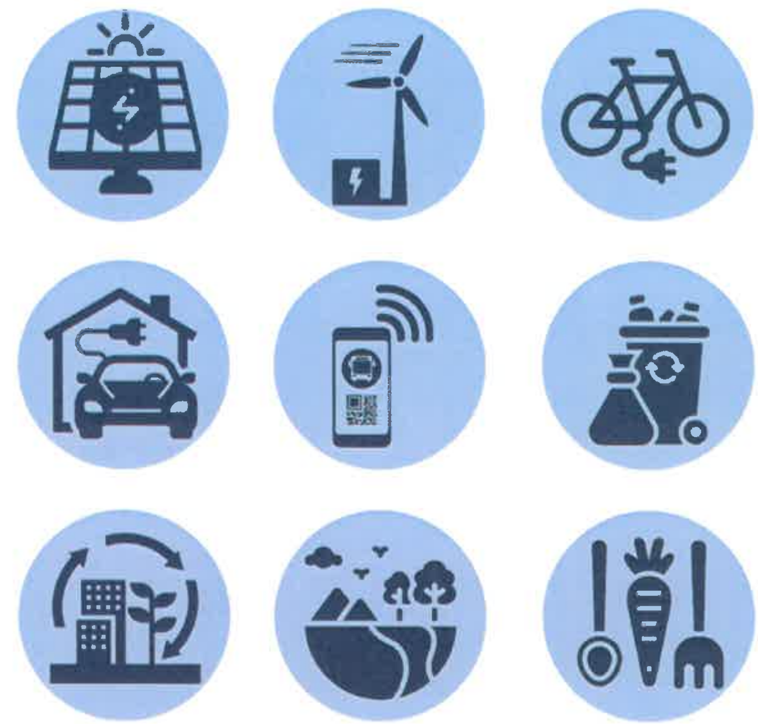
- regulatory and economic instruments have **already proven effective** in reducing emissions
- **policy packages** and **economy-wide packages** are able to achieve **systemic change**
- ambitious and effective mitigation requires **coordination across government** and society

[World Bank/Simone D. McCourtie, Dominic Chavez CC BY-NC-ND 2.0, Trent Reeves/MTA Construction & Development CC BY 2.0, IMF Photo/Tamara Merino CC BY-NC-ND 2.0, Olga Delawrence/Unsplash]

Technology and Innovation

- investment and policies **push forward low emissions** technological **innovation**
- **effective decision making** requires assessing potential benefits, barriers and risks
- **some options** are technically **viable**, rapidly becoming **cost-effective**, and have relatively **high public support**. Other options face barriers

Adoption of low-emission technologies is slower in most developing countries, particularly the least developed ones.

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Accelerated climate action is
critical to sustainable development
[Duy Pham/Unsplash]


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
7 AFFORDABLE AND CLEAN ENERGY
8 DECENT WORK AND ECONOMIC GROWTH
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

Mitigation options in urban areas

Relation with Sustainable Development Goals

	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17
Urban land use and spatial planning	+ (high)	• (high)	+ (high)	+ (medium)	+ (medium)	+ (high)	+ (high)	+ (high)	+ (high)	• (medium)	+ (high)	• (medium)	• (medium)	• (medium)	+ (medium)	
Electrification of the urban energy system	+ (medium)	• (medium)	+ (high)	+ (high)	+ (medium)	+ (medium)	+ (high)	+ (high)	+ (high)	+ (high)	+ (high)	• (medium)	+ (medium)	• (medium)	+ (medium)	
District heating and cooling networks	+ (medium)	– (medium)	+ (medium)				+ (medium)	+ (medium)	+ (medium)		+ (high)	+ (medium)		+ (high)	+ (medium)	
Urban green and blue infrastructure	+ (high)	+ (medium)	+ (high)	+ (medium)		+ (high)	+ (medium)	+ (medium)	+ (high)	• (medium)	+ (high)	+ (high)	+ (high)	+ (high)	+ (medium)	
Waste prevention, minimization and management	+ (high)	+ (medium)	• (medium)			+ (high)		• (medium)	+ (high)		+ (high)	• (high)	+ (high)	+ (high)	+ (medium)	
Integrating sectors, strategies and innovations	+ (high)	+ (high)	+ (high)	+ (high)	+ (medium)	+ (high)	+ (high)	+ (high)	+ (high)	+ (high)	+ (high)	+ (high)	+ (medium)	+ (high)	+ (medium)	+ (high)

Type of relations:
- + Synergies
- – Trade-offs
- • Both synergies and trade-offs[4]

Blanks represent no assessment[5]

Confidence level:
- *High confidence*
- *Medium confidence*
- *Low confidence*

Mitigation options in agriculture and forestry

Relation with Sustainable Development Goals	1	2	3	4	5	6	7	8	9	10	11	12	14	15	16	17
Carbon sequestration in agriculture[1]	+ (High)	+ (High)	• (Medium)			+ (High)		+ (Medium)				• (High)	+ (Medium)	+ (High)	+ (Medium)	
Reduce CH_4 and N_2O emission in agriculture		• (Low)	+ (High)			• (Low)			• (Low)			+ (Medium)	+ (High)	+ (High)		
Reduced conversion of forests and other ecosystems[2]	• (Medium)	− (Medium)	+ (High)			+ (High)		• (Medium)			• (High)		+ (High)	+ (High)	• (Medium)	• (Low)
Ecosystem restoration, reforestation, afforestation	+ (Medium)	• (Medium)	+ (Medium)			• (Medium)		− (Medium)		• (Low)	+ (High)		+ (High)	+ (Medium)		
Improved sustainable forest management	+ (High)	• (Low)	+ (Low)			+ (Medium)	• (High)	+ (Medium)	+ (High)	• (Low)	• (Medium)		+ (Medium)	+ (High)		
Reduce food loss and food waste	+ (High)	+ (High)	+ (High)			+ (High)	+ (High)			+ (Low)	+ (Low)	+ (High)	+ (Medium)	+ (High)	+ (Medium)	
Shift to balanced, sustainable healthy diets	• (Medium)	+ (Low)	+ (High)			+ (High)	+ (High)		• (Medium)	+ (Low)	+ (Low)	+ (High)	+ (Medium)	+ (High)		
Renewables supply[3]	• (Medium)	• (Medium)	• (Medium)			• (Medium)	• (Medium)	+ (Medium)	+ (High)				• (Medium)	• (Medium)		

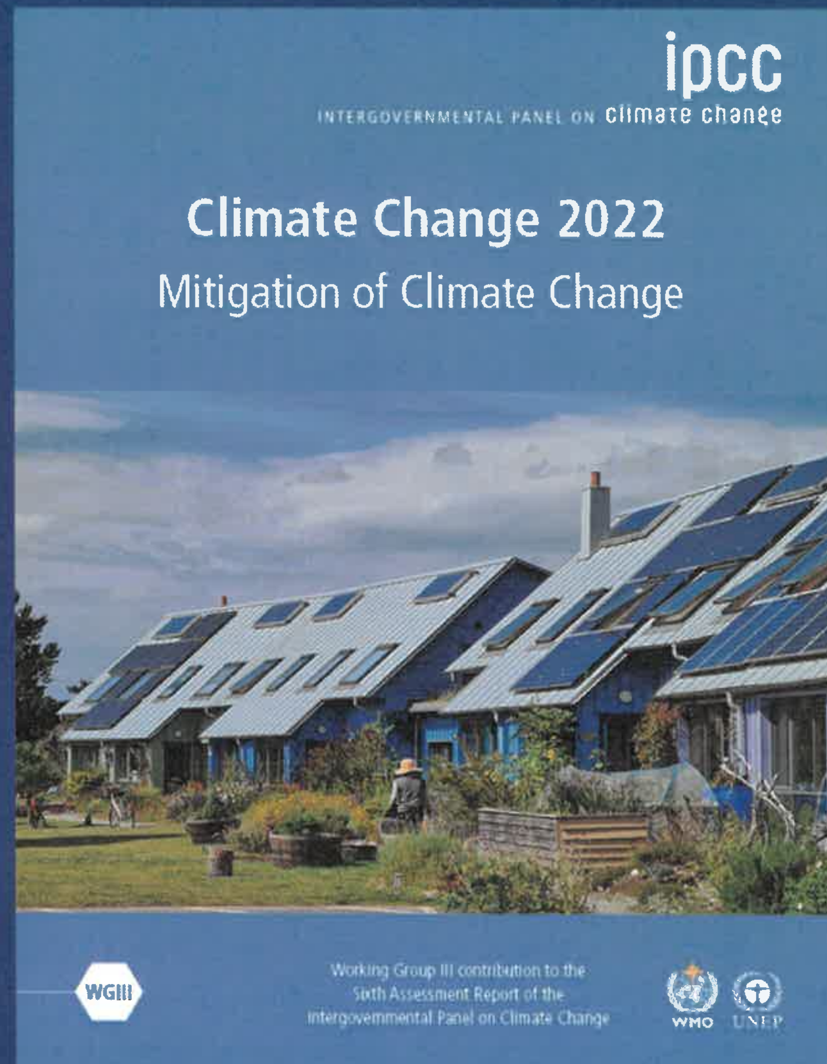
Type of relations:
- + Synergies
- − Trade offs
- • Both synergies and trade-offs[4]

Blanks represent no assessment[5]

Confidence level:
- *High confidence*
- *Medium confidence*
- *Low confidence*

Sixth Assessment Report
WORKING GROUP III – MITIGATION OF CLIMATE CHANGE

“The evidence is clear: The time for action is now



[Matt Bridgestock, Director and Architect at John Gilbert Architects]

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Limiting Global Warming: AFOLU Agriculture, Forestry and Other Land Uses

Land is currently a carbon sink, absorbing around 1/3 of human-caused emissions. Many mitigation options are available and ready to deploy but concerted, rapid and sustained effort by all stakeholders is a pre-requisite to achieving high levels of mitigation. Mitigation in this sector can't compensate for inaction in other sectors.

EMISSIONS SHARE

CO_2 emissions from deforestation have generally declined, with substantial differences by region.

CH_4 Methane emissions continue to increase, mostly due to livestock and farming related activities, such as manure management and rice cultivation.

N_2O Nitrous oxide emissions are increasing, mostly due to nitrogen fertiliser use.

GETTING TO NET ZERO EMISSIONS

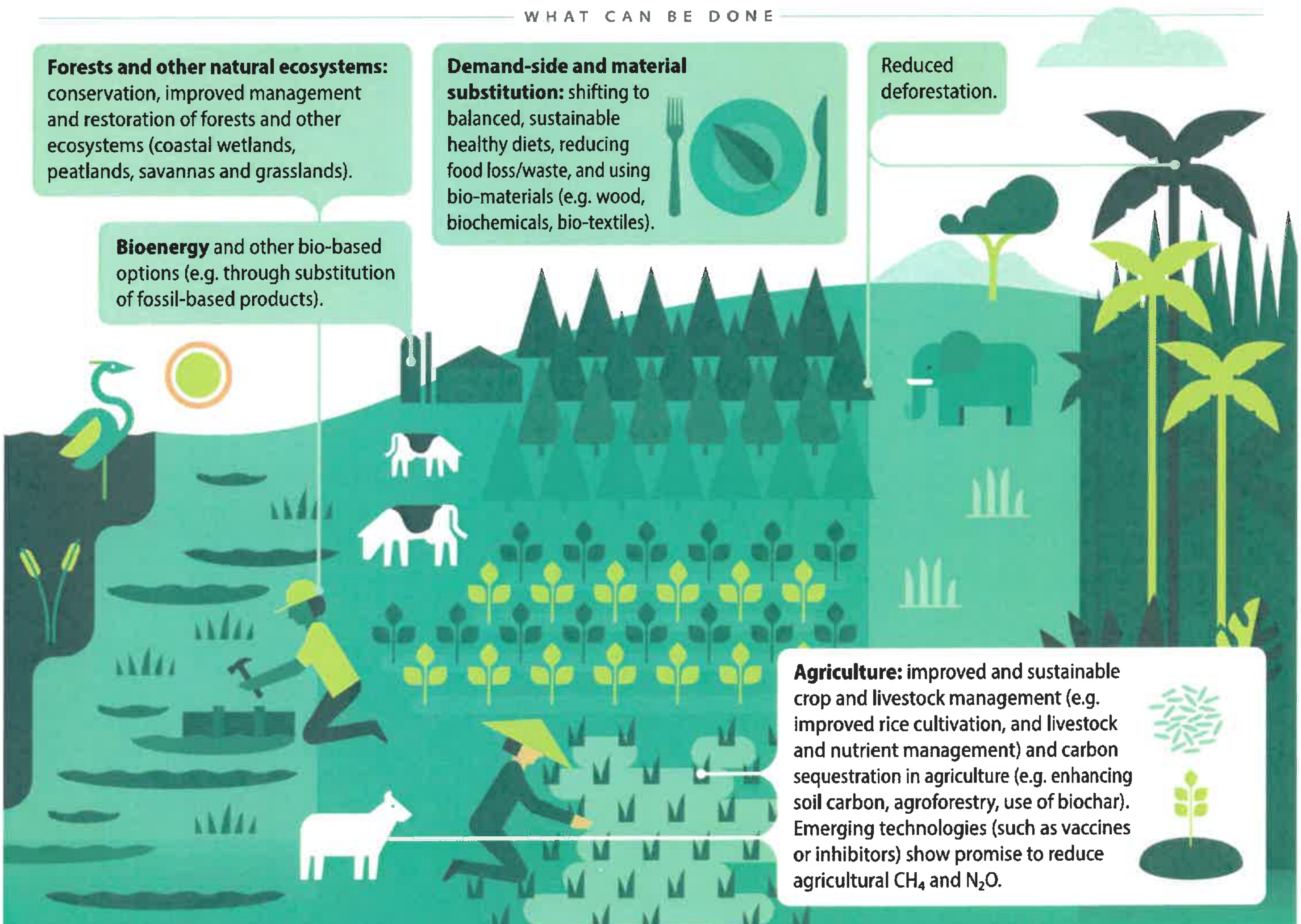
Mitigation options involve both reducing emissions and sequestering carbon (capturing carbon in the atmosphere and storing it on land and in products, such as harvested wood products like furniture and building materials).

Potential: AFOLU policies have mitigated about 1.4% of global emissions, but the sector can provide 20–30% of the mitigation needed for a 1.5°C or 2°C pathway towards 2050.

Low-cost options: Largest share of low cost options consist of reducing deforestation in combination with reforestation and sustainable forest management. This is followed by options in agriculture and demand-side measures.

Achieving net zero greenhouse gas emissions globally generally relies on reaching net negative CO_2 emissions from AFOLU.

WHAT CAN BE DONE



Forests and other natural ecosystems: conservation, improved management and restoration of forests and other ecosystems (coastal wetlands, peatlands, savannas and grasslands).

Demand-side and material substitution: shifting to balanced, sustainable healthy diets, reducing food loss/waste, and using bio-materials (e.g. wood, biochemicals, bio-textiles).

Reduced deforestation.

Bioenergy and other bio-based options (e.g. through substitution of fossil-based products).

Agriculture: improved and sustainable crop and livestock management (e.g. improved rice cultivation, and livestock and nutrient management) and carbon sequestration in agriculture (e.g. enhancing soil carbon, agroforestry, use of biochar). Emerging technologies (such as vaccines or inhibitors) show promise to reduce agricultural CH_4 and N_2O.

Mitigation options have synergies, risks and trade-offs with ecosystem services and sustainable development goals. Mitigation efforts should maximise synergies and minimise trade-offs.

ENABLERS

Recognising and respecting diverse forms of knowledge: Indigenous Peoples, private forest owners, local farmers, and communities manage a significant share of global forests and agricultural land and play a central role in land-based mitigation options.

Drawing on **past experience with regulations, policies, economic incentives, and payments;** examples include establishing and respecting tenure rights and community forestry, improved agricultural management and sustainable intensification, biodiversity conservation, and payments for ecosystem services.

Governance emphasising **integrated land-use planning.** E.g. In agriculture and forestry, approaches that consider biomass, food and timber production alongside ecosystem services can deliver multiple Sustainable Development Goals.

Context-specific policies and measures have been **effective** in demonstrating AFOLU mitigation options, but some constraints hinder their application at large scales.

BARRIERS

Economic and political feasibility are hampered due to, for example, weak governance, insecure land ownership, low incomes and the lack of access to alternative sources of income, the risk of policy reversal, and lack of accountability and institutional capacity.

Cost of mitigation options and **insufficient institutional and financial support.** The investment gap is wide for all sectors, but widest for AFOLU. Current government funding efforts are insufficient to realise the sector's economic potential. A gradual redirection of existing agriculture and forestry subsidies would greatly advance mitigation.

- Limited access to **technology, data, and know-how**
- **Reconciling alternative methods for calculating** emissions and sinks of human caused CO_2 on land greatly enhances the credibility of AFOLU-based emissions offsetting. It would also assist in assessing collective progress in a global stocktake.

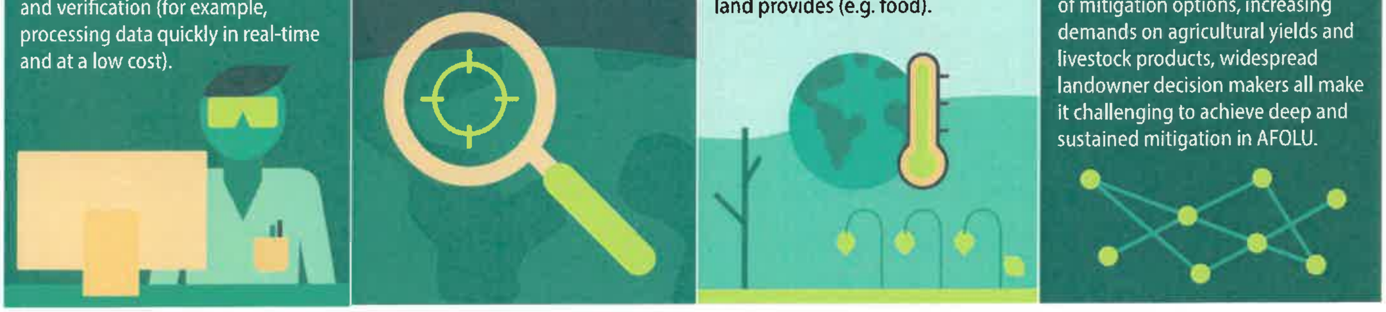
USD 400 billion per year by 2050 would be needed for the AFOLU sector to cover the investment gap.

Research priorities include better understanding of the impacts of climate change on mitigation potential, and improved measurement, reporting and verification (for example, processing data quickly in real-time and at a low cost).

Targeted research is needed to develop appropriate country-level, locally specific, policy and land management response options.

Climate change itself may threaten the capacity of the land to support both mitigation functions and other services land provides (e.g. food).

Differences in cultural values, diversity and complexity of agricultural systems and consumer contexts, maximising synergies and minimising trade-offs of mitigation options, increasing demands on agricultural yields and livestock products, widespread landowner decision makers all make it challenging to achieve deep and sustained mitigation in AFOLU.



LINKAGES

Co-benefits: Sustainable **intensification** of **agriculture,** shifting to balanced and sustainable healthy diets, and reducing **food waste** could enhance efficiencies and **reduce agricultural land needs.** These are critical for **enabling supply-side measures** such as **reforestation,** restoration, as well as **decreasing methane and nitrous oxide** emissions from agricultural production.

Trade-offs: AFOLU mitigation options that **compete** for land and land-based resources (such as biomass for energy) can pose **risks,** e.g. for food and water security, wood supply, livelihoods and land tenure and land-use rights of Indigenous Peoples, local communities and small land owners. Risks vary depending on the activity undertaken, context, and time frame, but **can be avoided when activity is pursued in response to the needs and perspectives of multiple stakeholders** to achieve outcomes that maximize co-benefits while limiting trade-offs.

To read full AR6 Working Group III report, please visit www.ipcc.ch/report/ar6/wg3

ipcc INTERGOVERNMENTAL PANEL ON climate change

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Limiting Global Warming: Urban Systems

All types of cities – whether established, rapidly growing, or emerging, can contribute to mitigating climate change through sustainable production and consumption, changes in demand, electrification, and improving urban carbon uptake and storage.

CURRENT EMISSIONS

2/3 global emissions can be attributed to urban areas including both goods and services produced in cities or imported from elsewhere

Emissions from urban areas are driven by population size, income, and the state of urbanisation and urban form

FUTURE OF CITIES

- With no urban mitigation efforts, urban emissions could more than double from 2020 levels.
- Aggressive but not immediate urban mitigation policies could limit global warming to 2°C.
- Aggressive and immediate mitigation policies could limit global warming below 1.5°C by the end of the century.

WHAT CAN BE DONE

How cities and towns are designed, constructed, managed, and powered will lock-in behaviour, lifestyles, and future urban emissions. Urban land areas could triple between 2015 and 2050, with significant implications for future carbon lock-in.

Established cities

Emissions can be reduced by 23-26% by 2050 and offer public health benefits. Options include:

- Improved land use and rezoning, e.g. through spatial planning for compact and resource-efficient cities
- Breaking out of lock-in – e.g. by replacing, improving or retrofitting buildings.
- Electrifying the grid – and employing low emissions public transport.

Rapidly growing cities

Designing human-centered streets and infrastructure layout is essential for lowering urban demand for energy and achieving low- or net-zero carbon.

- Employing low-emissions materials and reducing embodied emissions.
- E.g. going straight to electrification of urban services, like transport, heating, cooking etc.
- E.g. with urban planning for compact urban areas and co-locating homes with jobs

New cities

These yet-to-be-built cities have tremendous opportunity for low emission design and construction. Achieving this provides benefits for health and economic development.

- Smaller-scale, walkable cities
- Reducing materials demand and use

Urban green and blue infrastructure (in all cities): Urban forests, street trees, green roofs and other permeable surfaces can directly mitigate climate change by sequestering and storing carbon. They can also indirectly help by creating a cooling effect which reduces demand for energy and water.

OTHER BENEFITS

Green and blue infrastructure can help in reducing the urban heat island (UHI) effect and heat stress, reducing stormwater runoff, improving air quality, and improving the mental and physical health of people living in cities.

Measures that promote walkable urban areas combined with electrification and renewable energy can create health benefits from cleaner air and more physical activity.

MAKING IT HAPPEN

BEYOND CITY BOUNDARIES

Beyond city boundaries:
Cities can only achieve net zero emissions if emissions are reduced both within and outside of their administrative boundaries through supply chains (e.g. importing vehicles and building materials).

PARTNERSHIPS & COOPERATION

Addressing emissions beyond administrative boundaries depends on cooperation with national and subnational governments, industry, and civil society.

Putting in place infrastructure to mitigate climate change is often beyond the capacity of local budgets and jurisdictions.

INVESTING IN CITIES

Partnerships, e.g. between cities, institutions, regional governments, transnational networks etc. play a pivotal role in mobilising global climate finance. Current investment in urban areas is only 10% of the climate finance required for low-carbon urban development.

LINKAGES TO OTHER SECTORS

The implementation of packages of multiple city-scale mitigation strategies can have cascading effects across sectors and reduce GHG emissions both within and outside of a city's administrative boundaries.

Consumer behaviour & Transport

Changes in urban form (e.g. density, connectivity, and accessibility) in combination with programmes that encourage changes in consumer behaviour (e.g. transport pricing) could reduce transport related emissions in developed countries and slow growth in emissions in developing countries.

Land and Agriculture

Expansion of Urban areas is likely to take place on agricultural lands and forests, with implications for the loss of carbon stocks and sequestration.

To read full AR6 Working Group III report, please visit www.ipcc.ch/report/ar6/wg3

ipcc INTERGOVERNMENTAL PANEL ON climate change

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Limiting Global Warming: Transport

Electrification will play the key role in reducing emissions from land-based transport, but biofuels and hydrogen could play a role in decarbonisation of freight, and particularly in Shipping and Aviation.

THE BIG PICTURE

Emission Share & Breakdown

Emission Growth

2% Annually

Emissions from shipping and aviation continue to grow rapidly.

Greatest Mitigation Potential

Electrification

Alternative fuels

Net Zero

The transport sector is unlikely to reach net zero CO_2 emissions so carbon dioxide removal is likely needed to counterbalance residual CO_2 emissions from the sector.

Limiting warming to 1.5C with no or limited overshoot likely requires a 40% to 70% reduction in transport emissions by 2050, compared to 2020.

Limiting warming to 2C likely requires a 15% to 45% reduction in transport emissions by 2050, compared to 2020.

WHAT CAN BE DONE

Investment: to increase the scale of electric vehicles.

Governance: better national and international governance would help to decarbonise shipping and aviation. Examples include stricter efficiency or carbon intensity standards.

Batteries for electric vehicles:
- Reductions in the greenhouse gas footprint of battery production
- Solving concerns about critical materials needed for batteries (Examples include diversifying supply/ materials, recycling materials, or using them more efficiently).

Production process improvements and cost reduction for: sustainable biofuels, low emissions hydrogen, and synthetic fuels.

Technology: advances in battery technologies could help with the electrification of heavy-duty trucks.

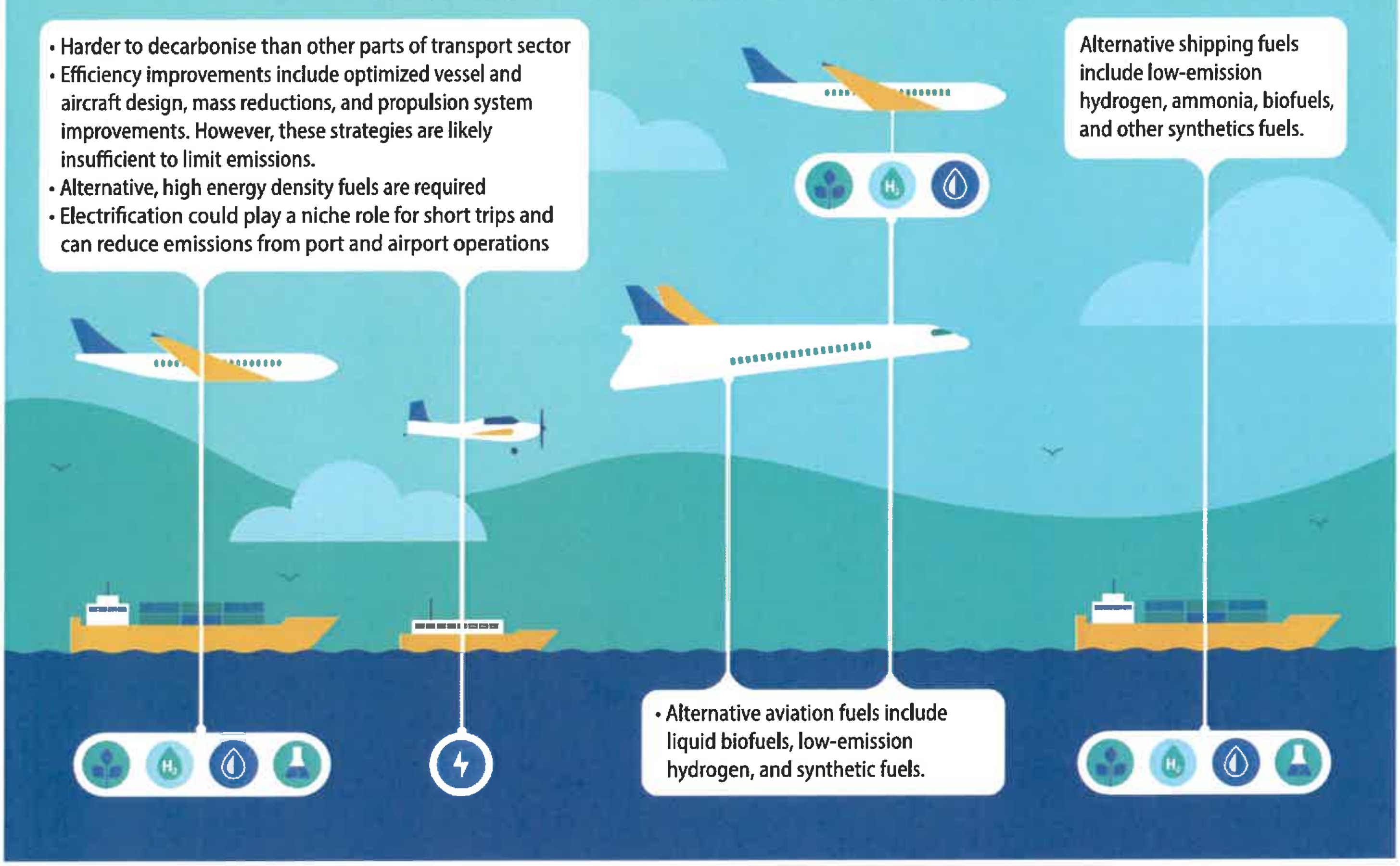
Consumer behaviour and demand for transport services is integral to decarbonisation of the sector. Options include:
- transport pricing and shifting to energy-efficient transport
- Reducing demand for transporting people and products, through systemic changes such as teleworking, digitalisation, supply chain management, and shared mobility.

Emissions reductions will vary by region.

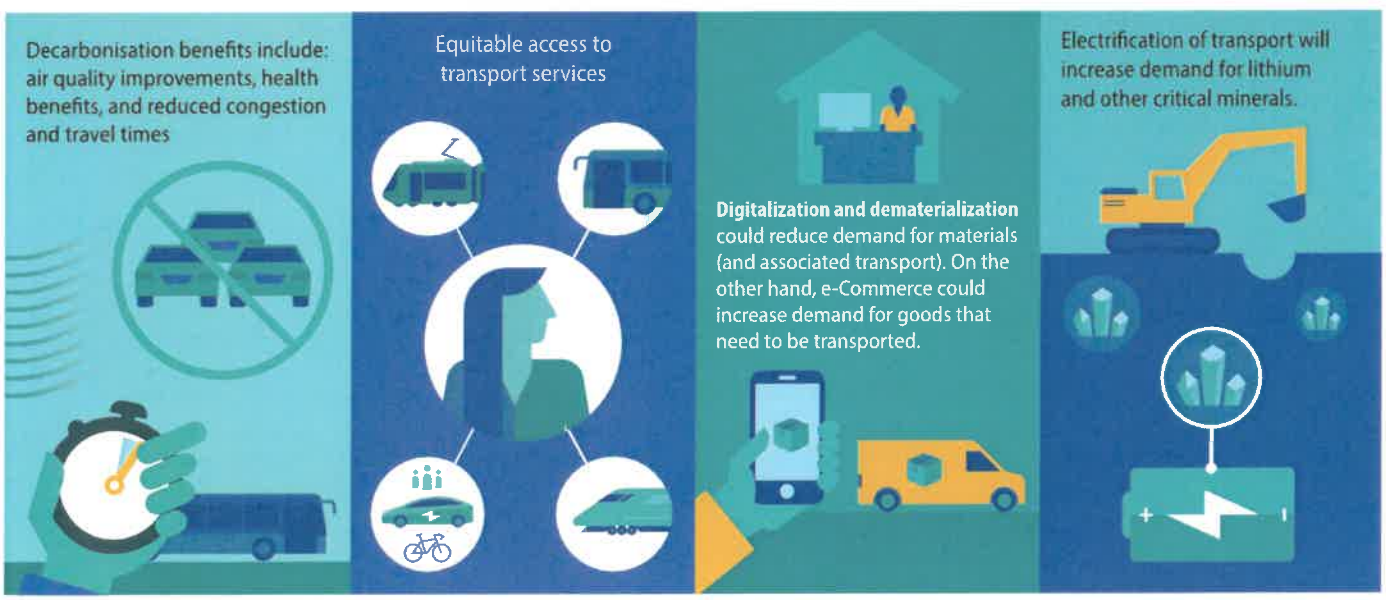
Developing countries: Technology transfer and financing can support developing countries transition or go directly to low emissions transport systems.

Electrification: In land-based transport, electric vehicles powered by low emissions electricity offer the largest decarbonisation potential

WHAT CAN BE DONE (SHIPPING AND AVIATION)



BENEFITS AND TRADE-OFFS



LINKAGES

Cities

Supporting public transport, cycling, and walking can lead to large emissions savings. Making cities more compact and providing infrastructure that is less car-dependent can reduce emissions from transport fuel consumption by 25%!

Energy

Reducing emissions from the transport sector largely depends on power sector decarbonisation, and low emissions feedstocks (for biofuels) and production chains.

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Limiting Global Warming: Buildings

Action in 2020-2030 is critical to fully capture the mitigation potential of existing and new buildings. In developing countries, the largest potential is in new buildings, while in developed countries the highest potential is within the retrofit of existing buildings.

EMISSIONS SHARE

21% of global GHG emissions linked to the buildings sector

- 18% Embodied emissions from cement and steel
- 24% Direct emissions
- 57% Indirect emissions

CO_2 emissions from buildings have increased by 50% (1990-2019) due to the increase of the floor space per capita in the global North, population growth, and increased access to energy using fossil fuels e.g. electricty/ heating.

GETTING TO NET ZERO EMISSIONS

Approaching net zero emissions in 2050 can be achieved through ambitious policy packages e.g. urban planning, efficient design and use of space, energy, materials, and appliances, and incorporating use of renewables.

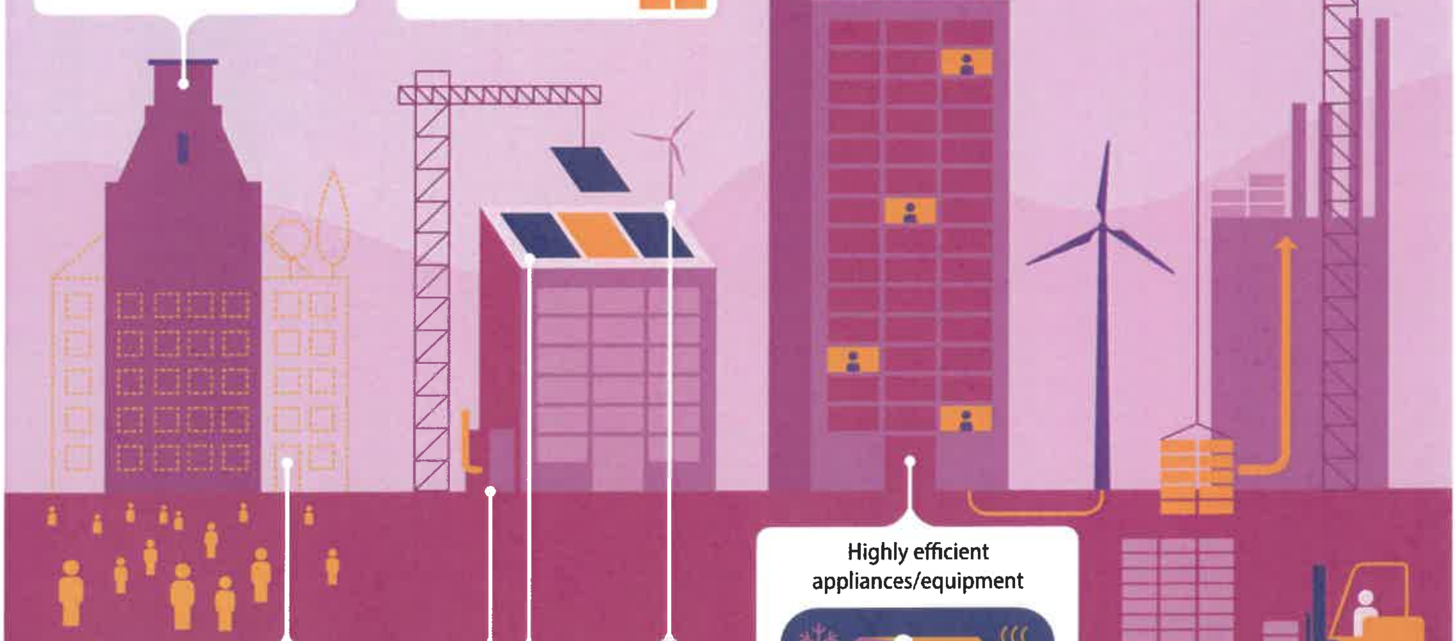
61% from demand side measures | 29% from the decarbonisation of electricity, heat and cold produced offsite

By 2050, the 61% of demand-side mitigation potential includes:

- 10% from **Sufficiency interventions.** (Sufficiency policies are a set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human wellbeing for all within planetary boundaries)
- 42% from **energy efficiency** interventions
- 9% from **renewable energy** building-integrated renewable energy interventions

WHAT CAN BE DONE

Design stage: → **Construction stage:** → **Use stage:** → **Disposal stage:**



Design stage:

- Urban planning that allows for bioclimatic design.
- Repurposing unused existing buildings to avoid using emission-intensive materials and additional land.
- Considering the building's form and multi-functionality to allow for the evolving needs of their users

Construction stage:

- Employing highly efficient building envelope (e.g. walls, floors, roofing, doors)
- Using low-emission construction materials
- Integrating renewable energy, such as solar photovoltaics, small wind turbines, solar thermal collectors, and biomass boilers.

Use stage:

- Energy supply from low-emission energy sources
- Highly efficient appliances/equipment
- Optimising how the building is used e.g. using daylight instead of artifical light

Disposal stage:

- Recycling and re-using construction materials

WHAT ELSE CAN WE DO?

Building energy codes (e.g. for insulation) are especially effective if compulsory and combined with other regulatory instruments such as minimum energy performance standards for appliances and equipment.

Limiting the **use of land,** property taxes to limit urban sprawl, and prioritising multi-family buildings over single-family homes.

Reduce demand for cooling, heating, ventilation, and artificial lighting through sufficiency measures such as bioclimatic design (considering the expected future climate), nature based solutions (e.g. green roofs), and white walls.

ENABLERS

Building technical and institutional capacity, developing skills, setting appropriate governance structures, and ensuring the flow of finance can help achieve mitigation potential.

BARRIERS

Global investment in the decarbonisation of buildings was estimated at USD164 billion in 2020, which is not enough to close the investment gap. Between 2026-2030 annual investment needs are estimated at USD711 billion.

Increasing size of dwellings despite smaller households, especially in developed countries

Low renovation rates and low ambition for renovation work in developed countries

Reliance on fossil fuels for electricity and heating

Increase in use and size of appliances, especially ICT and cooling, driven by higher incomes.

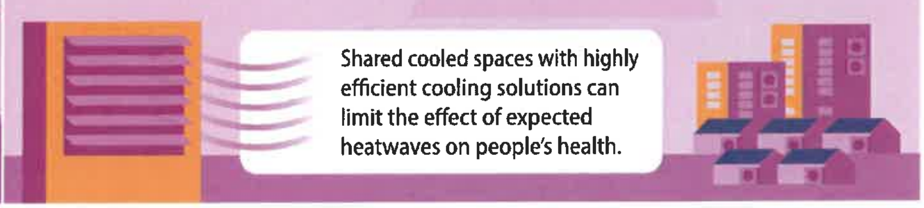
Inefficiency of new buildings, especially in developing countries

Lack of appropriate governance structures and institutional capacity

CLIMATE IMPACTS AND ADAPTATION

Global warming will lead to changes in temperature and humidity, and sea level rise. This will impact the need for cooling and heating, as well as the performance, durability, and safety of buildings.

Measures to cope with climate change (e.g air conditioning) may increase the demand for energy and materials from buildings leading to an increase in GHG emissions if not mitigated.



Shared cooled spaces with highly efficient cooling solutions can limit the effect of expected heatwaves on people's health.

SUSTAINABLE DEVELOPMENT

Beyond SDG 13, actions in the building sector contribute to meeting fifteen other SDGs. These include health gains through improved indoor air quality and thermal comfort, job creation, reduced poverty (especially energy poverty), and improved energy security.

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Limiting Global Warming: Energy

Warming cannot be limited to well below 2°C without rapid and deep emissions reductions from the energy system and substantial changes over the next 30 years. This will involve a significant reduction in overall fossil fuel use, use of carbon capture and storage, low- or no-carbon energy systems, widespread electrification, use of alternative fuels such as hydrogen and sustainable biofuels, and improved energy efficiency.

THE BIG PICTURE

Emissions from fossil fuels:

34% of all emissions come from the energy sector (2019)

Demand for energy continues to rise with energy emissions growing by 2.7%

CH_4

18% Overall, methane accounted for 18% of all emissions in 2019 – these are mainly fugitive emissions from oil, gas, and coal. That is, greenhouse gases released during the exploration, processing and delivery of fossil fuels to the point of final use.

Coal

Gas

Oil

7.5% **Growth in coal electricity capacity** Growth in building of new coal-fired power plants increased in some countries, offsetting the decline in others.

15% increase in consumption of natural gas

5% increase in consumption of oil and oil products

Low and zero carbon energy sources:

Fuels **37%** of global electricity (2019)

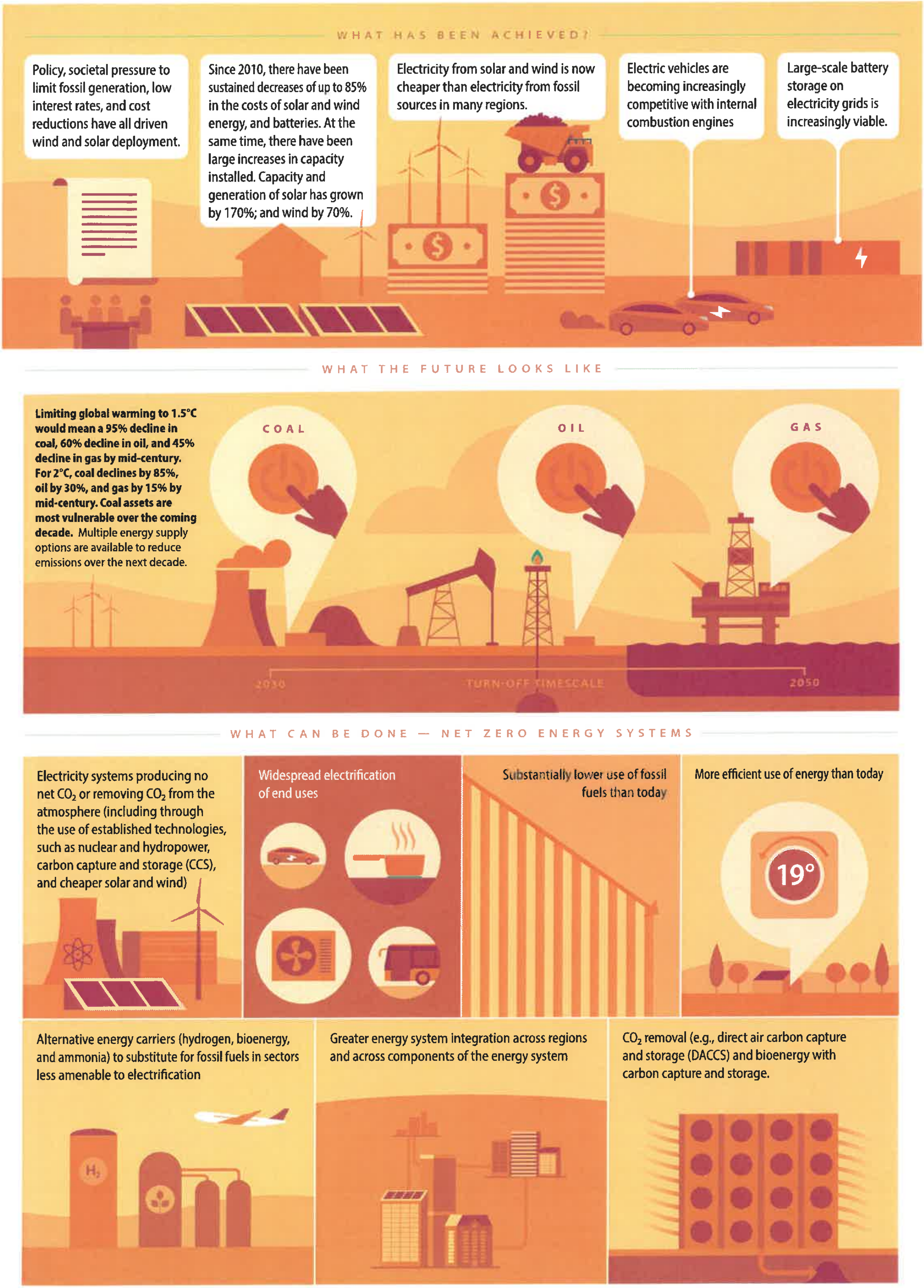
8-10% Growth in low and zero carbon power

16% Comes from hydroelectric power (2019)

10% comes from nuclear

10% of primary energy is from bioenergy

8% of all electricity comes from solar and wind


WHAT HAS BEEN ACHIEVED?
Policy, societal pressure to limit fossil generation, low interest rates, and cost reductions have all driven wind and solar deployment.
Since 2010, there have been sustained decreases of up to 85% in the costs of solar and wind energy, and batteries. At the same time, there have been large increases in capacity installed. Capacity and generation of solar has grown by 170%; and wind by 70%.
Electricity from solar and wind is now cheaper than electricity from fossil sources in many regions.
Electric vehicles are becoming increasingly competitive with internal combustion engines
Large-scale battery storage on electricity grids is increasingly viable.
WHAT THE FUTURE LOOKS LIKE
Limiting global warming to 1.5°C would mean a 95% decline in coal, 60% decline in oil, and 45% decline in gas by mid-century. For 2°C, coal declines by 85%, oil by 30%, and gas by 15% by mid-century. Coal assets are most vulnerable over the coming decade. Multiple energy supply options are available to reduce emissions over the next decade.
COAL
OIL
GAS
2030
TURN-OFF TIMESCALE
2050
WHAT CAN BE DONE — NET ZERO ENERGY SYSTEMS
Electricity systems producing no net CO_2 or removing CO_2 from the atmosphere (including through the use of established technologies, such as nuclear and hydropower, carbon capture and storage (CCS), and cheaper solar and wind)
Widespread electrification of end uses
Substantially lower use of fossil fuels than today
More efficient use of energy than today
19°
Alternative energy carriers (hydrogen, bioenergy, and ammonia) to substitute for fossil fuels in sectors less amenable to electrification
H_2
Greater energy system integration across regions and across components of the energy system
CO_2 removal (e.g., direct air carbon capture and storage (DACCS) and bioenergy with carbon capture and storage.

ENABLERS, BENEFITS AND OPPORTUNITIES

Finance and investment: A low-carbon energy transition will shift investment patterns and create **new economic opportunities.**

- To likely limit warming to 2°C or below, total **energy investment needs will rise,** relative to today, over the next decades.
- These increases will be far less pronounced than the reallocations of investment flows. Reallocations of investment will be away from fossil fuels (extraction, conversion, and electricity generation) without CCS and toward renewables, nuclear power, CCS, electricity networks and storage, and end-use energy efficiency.
- A significant and growing share of investments between now and 2050 will be made in emerging economies, particularly in Asia.

Several mitigation options are technically viable, are becoming increasingly cost effective, and are generally supported by the public. This enables deployment in many regions. Some options have other environmental and health benefits, such as improved air quality and reduced toxic waste.

Greater integration between the electricity sector and end use sectors can facilitate integration of variable renewable energy (VRE) options. Energy systems can be integrated across district, regional, national, and international scales. This will lower costs and facilitate the transition to a low-carbon system.

The economic outcomes of low-carbon transitions in some sectors and regions may be on a par with, or superior to those of an emissions-intensive future.

BARRIERS

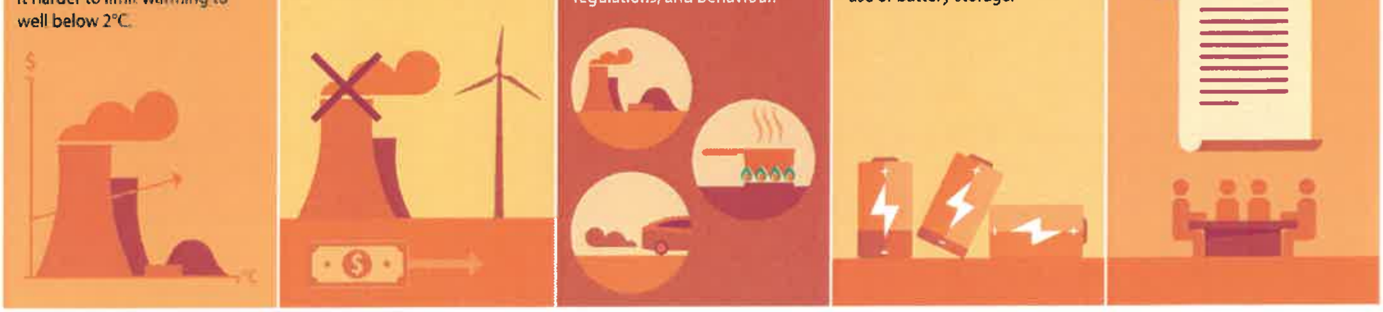
If investments in coal and other fossil infrastructure continue, energy systems will be locked in to higher emissions, making it harder to limit warming to well below 2°C.

New investments in coal-fired electricity without CCS are inconsistent with limiting warming to well below 2°C.

Resistance or slow to change aspects of the energy system, e.g. physical infrastructure; institutions, laws, and regulations; and behaviour.

Environmental impacts associated with some mitigation options require managing, such as large scare use of battery storage.

Institutional barriers need to be addressed to enable application of mitigation options at scale.



CHALLENGES

Need to address the geophysical, environmental-ecological, economic, technological, socio-cultural, and institutional factors that can facilitate or hinder implementation of low or no carbon options.

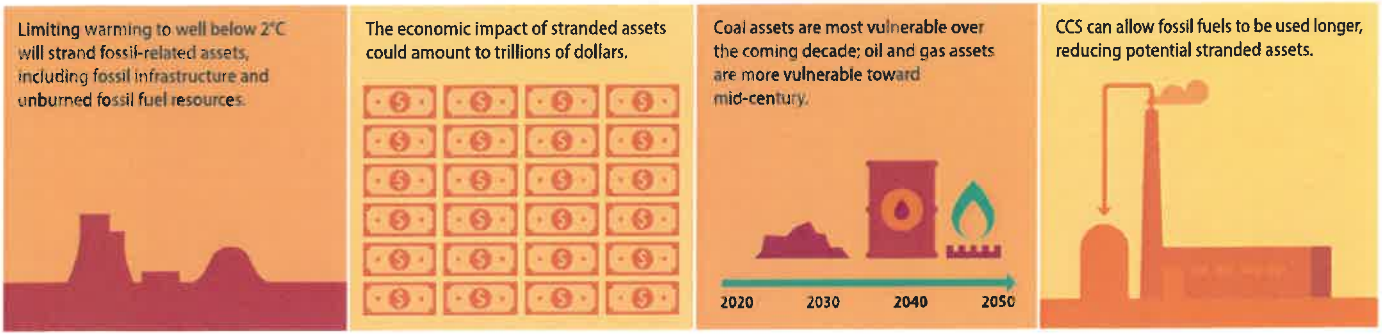
Electricity systems powered by renewables are becoming increasingly viable, but it will be challenging to supply the entire energy system in this way.

Majority of solar and wind power can be incorporated in electricity grids through batteries, hydrogen, and other forms of storage/transmission.

Since some applications (e.g., air travel) are not currently amenable to electrification, net zero energy systems would likely need to include alternative fuels such as hydrogen or biofuels.

Higher shares of renewable electricity and energy are associated with increased economic, regulatory, social, and operational challenges. How to overcome all of these challenges in practice is not yet fully understood.

TRADE-OFFS



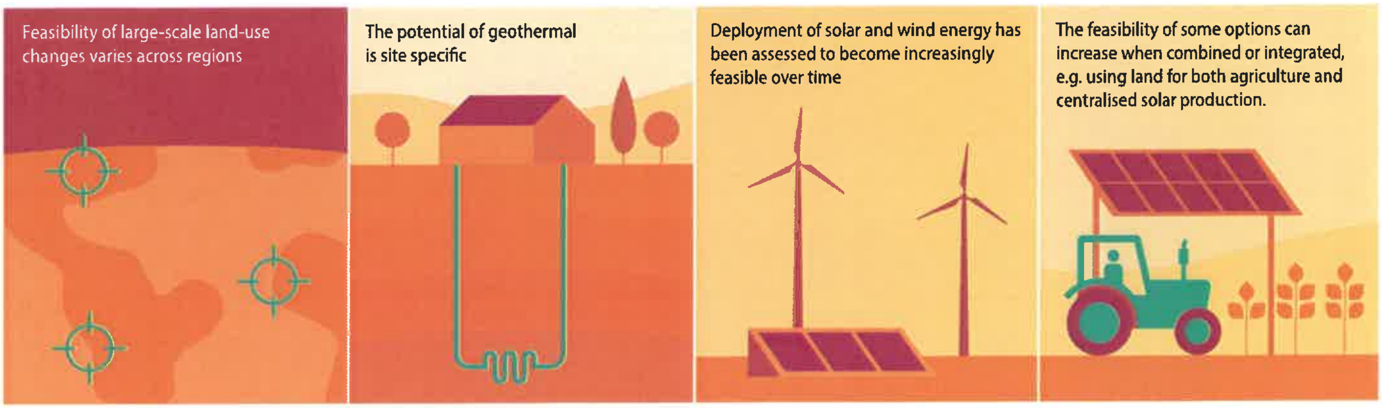
Limiting warming to well below 2°C will strand fossil-related assets, including fossil infrastructure and unburned fossil fuel resources.

The economic impact of stranded assets could amount to trillions of dollars.

Coal assets are most vulnerable over the coming decade; oil and gas assets are more vulnerable toward mid-century.

CCS can allow fossil fuels to be used longer, reducing potential stranded assets.

FEASIBILITY OF MITIGATION OPTIONS VARIES ACCORDING TO CONTEXT AND TIME



Feasibility of large-scale land-use changes varies across regions

The potential of geothermal is site specific

Deployment of solar and wind energy has been assessed to become increasingly feasible over time

The feasibility of some options can increase when combined or integrated, e.g. using land for both agriculture and centralised solar production.

LINKAGES

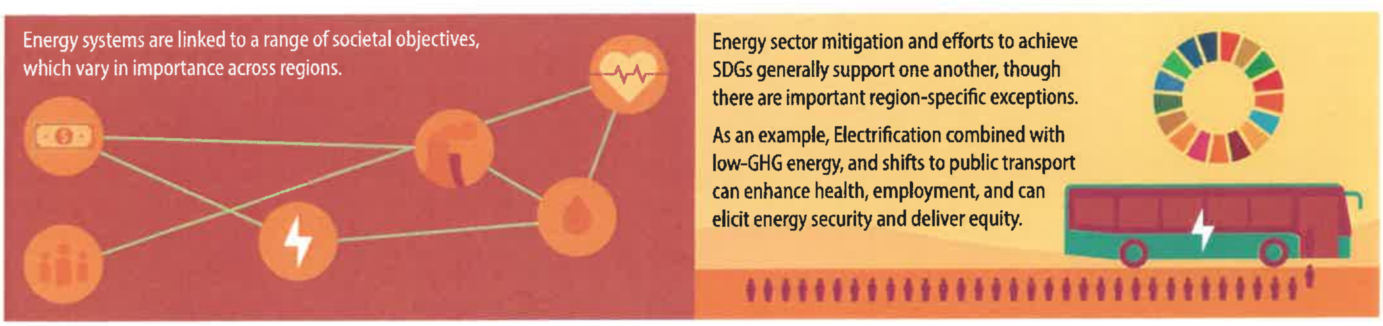
International trade: A low-carbon energy sector transition is expected to reduce international trade in fossil fuels. There may be trade in other types of energy (such as hydrogen) and large-scale bioenergy production is likely to trigger global biomass trade.

Transport: Electric vehicles powered by low-emissions electricity offer the largest decarbonisation potential for land-based transport, on a life cycle basis.

Buildings: 61% of emissions from buildings could be mitigated by 2050. 10% from **Sufficiency policies** (set of measures and daily practices that avoid demand for energy, materials, land and water while delivering human wellbeing for all within planetary boundaries); 42% from **energy efficiency** policies; 9% from **renewable energy** policies.

SUSTAINABLE DEVELOPMENT

The viable speed and scope of a low-carbon energy system transition will depend on how well it can support sustainable development goals and other societal objectives.



Energy systems are linked to a range of societal objectives, which vary in importance across regions.

Energy sector mitigation and efforts to achieve SDGs generally support one another, though there are important region-specific exceptions.

As an example, Electrification combined with low-GHG energy, and shifts to public transport can enhance health, employment, and can elicit energy security and deliver equity.

KNOWLEDGE GAPS AND ADVANCES REQUIRED

Long-term mitigation costs are not well understood and depend on policy design and implementation, and the future costs and availability of technologies.

Advances in low-carbon energy resources and carriers such as next-generation biofuels, hydrogen produced from electrolysis, synthetic fuels, and carbon-neutral ammonia would substantially improve the economics of net-zero energy systems.

To read full AR6 Working Group III report, please visit www.ipcc.ch/report/ar6/wg3

ipcc INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

THIS FACTSHEET WAS FUNDED BY THE NORWEGIAN ENVIRONMENT AGENCY

Norwegian Environment Agency

5 takeaways from the latest IPCC report

Apr 5, 2022

We can still meet climate targets if we completely transform our economic models and outlook on how we interact with Earth's resources.

Join us

Bronson Griscom

Senior Director, Natural Climate Solutions at Conservation International

Listen to the article

7 min listen

- **The latest IPCC report emphasizes the role of nature in addressing climate change.**
- **To confront rising temperatures, we must invest in nature-first solutions.**
- **We can still meet climate targets if we completely transform our economic models and outlook on how we interact with Earth's resources.**

Carbon emissions are rising. Countries are off track in delivering their climate pledges. Current commitments aren't enough to keep temperatures below critical thresholds. These are some of the findings from the latest report of the United Nations Intergovernmental Panel on Climate Change (IPCC).

It sounds grim. That's not the only news, though: With this report, we now have a global scientific consensus on the enormous impact nature could have in confronting the climate crisis.

IPCC Report 2022

Here are five takeaways from the IPCC about the critical role nature plays in stabilizing the climate:

1) Nature is the unseen solution

The most significant takeaway from today's IPCC report is how nature can act as a climate solution. The report details 43 cost-effective approaches to limiting global warming to less than 1.5°C (the safetybenchmark for a safe climate set by the Paris Agreement).

First and third on this list are solar and wind energy, respectively. The second, fourth, and fifth most effective strategies for mitigating carbon emissions are all natural climate solutions (reported within

Our prior research shows that natural climate solutions could provide about a third of the climate mitigation necessary to meet the goals of the Paris Agreement. This translates to over 10 billion metric tons of reduced carbon dioxide and other greenhouse gases per year. Today's IPCC report finds that natural climate solutions could, in fact, deliver between 11 to 14 billion metric tons of greenhouse gases per year.

2) Highly cost-effective yet underfunded

The IPCC finds that most of nature's potential contributions to solving climate change are cost-effective — though wildly underfunded. Delivering forest-related natural climate solutions to limit warming to less than 2°C would cost up to $400 billion a year by 2050. That's less than current subsidies for agriculture and forestry – many of which are incentives for outdated practices that increase emissions. Hence, re-allocation of existing funding to achieve climate smart economic growth in rural communities would deliver an important part of this funding gap.

The IPCC report 2022 finds that investments in natural climate solutions are up to 29-times less than what's needed to stabilise the climate. That is the largest funding gap of any sector, including significant, given forests' rapid growth rates and high risks of deforestation.

Have you read?

- **Global Risks Report 2022**
- **New Nature Economy Report Series**
- **BiodiverCities by 2030: Transforming cities' relationship with nature**

3) IPCC report wants the world to make proactive decisions

The IPCC report finds that the right kind of climate action can create a much better future than we imagine. Though climate change is driven by the world's wealthiest nations, its consequences are felt disproportionately by developing countries, who are far less responsible for it. Through proactive decision-taking, millions of people, especially vulnerable communities, can be protected against climate threats.

Nature-based solutions not only protect at-risk communities from the brunt of climate change, they're powerfully aligned with sustainable development goals. These include eliminating hunger and providing access to clean water. When we take action to mitigate climate change by protecting nature, we're also supporting nature-reliant communities. By doing this, we're making the world a healthier and more just place.

Similarly, actions that tackle climate change by conserving ecosystems can also tackle climate change. For example, Conservation International has found that many of Earth's largest and most critical carbon sinks, such as the Amazon rainforest and Congo Basin, overlap with high-biodiversity hotspots. Protecting lands essential for climate stability also conserves habitats for thousands of mammals, birds and reptiles.

Have you read?

- **How our economy could become more 'nature-positive'**
- **Nature-based solutions spending needs to rise four-fold. Here's how the G20 can lead by example**

4) It's "both/and" not "either/or"

As per the 2022 IPCC report, confronting the climate crisis requires a complete transformation of our energy sources, economic models and land stewardship. Decades ago, we may have been able to reduce fossil fuel emissions *or* implement natural climate solutions to stabilise our climate. Now, we only have one rational choice: We must rapidly decarbonise our economies *and* unlock natural climate solutions. The good news is that this great challenge also presents an opportunity to develop a better world.

5) We can do this

We know from earlier IPCC reports that we're falling behind in our climate commitments. Today's report has a bigger message: Nature provides major tools to put us back on track. The future we fear is not inevitable. Oceans, forests and other ecosystems already absorb and store about half of global carbon emissions. The despair we feel from climate projections must turn into action. Solving climate change is an opportunity to tackle problems we have struggled with for generations.

Along with decarbonizing our economies and pursuing carbon-capture technologies, governments must prioritise nature in their policy decisions. The private sector should urgently implement net-zero commitments with strong nature-based considerations.

The 2020s are critical. Change won't be easy, but we have no other choice. Either we allow our planet to be destroyed, or we fight – clear-eyed – for a better world. We can create a climate-resilient world with sustainable food production, clean air and abundant water resources. This IPCC report makes it very clear: Nature is on our side, we can't do this without her.

QUICKNOTES

Planning fundamentals for public officials and engaged citizens

This PAS QuickNotes was prepared by Larry Coffman, a leading national expert on LID and consultant specializing in LID education and training.

Low-Impact Development

WHAT IS LID?

Low-impact development (LID) is the general term for a wide array of site planning principles and engineered treatment practices used to manage both water runoff volume and water quality. LID is an ecologically friendly approach to site development and stormwater management. It encourages sustainability by minimizing development impacts to the land, water, and air. LID's goal is to use multiple on-site techniques to avoid generating runoff and increase the landscape's ability to detain rainwater and capture pollutants. Rather than rely on one single device for control, such as a detention pond, it relies on the cumulative benefits of many small-scale prevention and treatment techniques.

Larry Coffman

Tree box filters and infiltration parking areas along the roadway.

LID can be applied to any type of development. The key is to select the most appropriate LID principles and practices that work best for the particular hydrology and geology of the land. The goal is to mimic the unique water balance of a site. LID techniques are especially useful for urban retrofit and redevelopment projects and play an important role in restoring waters degraded by existing uncontrolled urban development. LID technology has been in practice for over 15 years. It has demonstrated its effectiveness in advancing long-term economic and environmental benefits, protecting sensitive aquatic resources, and supporting sustainability.

LID STRATEGIES AND TECHNIQUES

LID can be used in new development or urban retrofit and redevelopment settings. Applying LID to new development involves using a five-step systematic approach to reducing and controlling runoff. First, on a project scale, optimize conservation of natural features (trees, wetlands, streams, and special areas), drainage patterns, topography, and soils in defining the building envelope. The conservation areas are to be used to treat runoff using their natural ability to filter and soak up runoff. Second, at the individual lot level, minimize impacts by saving existing vegetation and soils, while limiting the use of impervious surfaces and pipes. Third, slow the water down by preserving the natural drainage pathways and use of vegetated swales. Fourth, compensate for runoff increases by using various LID-engineered practices such as rain gardens, infiltration practices, small-scale detention swales, and filtration practices. Fifth, prevent pollution by influencing human behavior through education to reduce the introduction of pollutants into the environment.

LID techniques are ideal for urban retrofit and redevelopment. The small-scale treatment practices can be easily integrated into the urban landscape by using tree box filters, bioretention landscaping, porous surfaces, and green roofs. LID practices now make it possible to reverse the impacts of existing uncontrolled urban development. It does this by replacing nonfunctional landscape features with multifunctional detention and filtration practices.

WHAT MAKES LID SO ATTRACTIVE?

A growing number of state and local programs are incorporating LID as a site planning principle due to its many benefits:

Universally Applicable. Regardless of climate, hydrology, or geology, there are many LID techniques that can be applied to meet stormwater goals.

Economically Sustainable. In many instances, the impacts from LID have been shown to be less costly to construct and maintain. Savings are typically achieved by reducing or eliminating the use of stormwater management ponds; minimizing reliance on pipes, inlet structures, curbs and gutters;

APA
American Planning Association
Making Great Communities Happen

and reducing roadway paving, grading, and clearing. LID's bottom line is environmentally friendly land development at less cost.

Environmentally Sustainable. LID's goal for new development is to mimic the natural water balance of the site. Careful use of LID will avoid adverse water quality and flooding impacts. Further, since LID relies to a great extent on natural vegetative practices, these techniques will work long-term to capture and cycle pollutants with only minimum landscape maintenance.

Multiple Design Benefits. Many LID techniques can reduce water consumption through the use of native plants to reduce the need for irrigation and by using rain barrels to capture and use runoff. Green roofs, with their insulation properties, can reduce heating and air conditioning costs. LID's use of vegetation can improve air quality, save energy, and improve aesthetics and property values.

Ideal for Urban Retrofit. LID practices have become a most useful tool for urban retrofit and redevelopment and are playing an important role in restoring waters degraded by existing uncontrolled urban development. Major cities, including Philadelphia, Washington, D.C., Milwaukee, and Portland, Oregon, are retrofitting their urban landscapes with LID practices to reduce the volume runoff and improve water quality, which can reduce combined sewer overflows and help meet receiving water quality goals.

Not a Growth Management Tool. LID is not a technique that affects growth management concerns such as the rate or location of growth, the overall density of new development, or the compactness of the settlement pattern. While conservation design and cluster development can have beneficial impacts on water retention and water quality, LID focuses on technology-based approaches that impact flooding and water quality.

REMAINING CHALLENGES

Today there are few technical challenges or barriers preventing LID's widespread use. Technical design guidance is available on all aspects of LID site planning, practice design and maintenance. Numerous manufacturers now provide many types of storage, filtration and infiltration practices such as porous surface systems, tree box filter systems, infiltration systems, bioretention soil mixtures, rainwater capture devices, and green roof systems. Regulatory guidance exists at the federal, state, and local levels. Monitoring and research has studied LID's performance, economics, maintenance needs, and design specifications.

The biggest challenge to full implementation of a LID approach is the effort required to overcome the inertia that prevents changes in conventional institutional thinking. LID is innovative and unconventional. Some of its principles and practices may conflict with existing stormwater management approaches, subdivision regulations, and building codes. Development of a LID program requires significant effort to address these conflicts and to provide new design guidance.

Getting LID institutionalized requires a collaborative effort between a variety of stakeholders—government, the development community, and environmental groups. The first step is to determine which LID principles and practices work best to meet local political, economic, and stormwater goals. This requires an open discussion of the best mix of prevention and conservation measures and engineered treatment practices. Once the LID principles have been defined the next step is to develop technical guidance. This must be customized to address local hydrology, geology, and climate issues and to resolve any technical conflicts with existing codes and regulations. This process can take one to two years to complete.

The bottom line: Low-impact development techniques should be considered important components in any community's strategy to advance sustainability and resilience.

"LID encourages sustainability by minimizing development impacts to the land, water, and air."

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2. Other Resources

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The Low Impact Development Center, Inc., http://www.lowimpactdevelopment.org.

Benefits of Low Impact Development

How LID Can Protect Your Community's Resources

LID Barrier Busters Fact Sheet Series

What Is Low Impact Development (LID)?

LID includes a variety of practices that mimic or preserve natural drainage processes to manage stormwater. LID practices typically retain rain water and encourage it to soak into the ground rather than allowing it to run off into ditches and storm drains where it would otherwise contribute to flooding and pollution problems (see **www.epa.gov/nps/lid**).

A green roof absorbs rainwater, reduces energy costs and offers wildlife habitat in urban Portland, Oregon.

Why Should My Community Adopt LID?

LID Reduces Stormwater Runoff by Emphasizing Infiltration

As a community grows, so does the amount of surface area covered by parking lots, roads and rooftops (Figure 1). Rainfall cannot soak through these hard surfaces; instead, the rain water flows quickly across them—picking up pollutants along the way—and enters ditches or storm drains, which usually empty directly and without treatment into local waterways. Local streams in urban areas are overwhelmed by frequent urban flash flooding and stream habitats are smothered by sediments carried by the excessive flows.

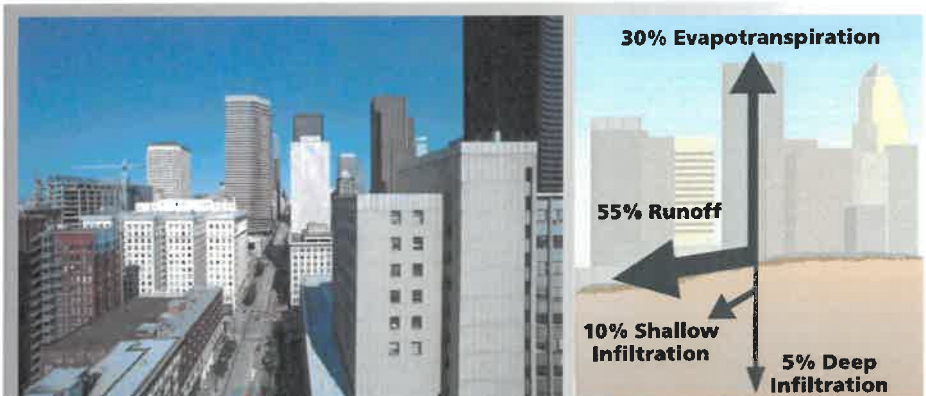

Figure 1. When roads, rooftops and parking lots cover much of the land, more than half of the rainfall runs off and flows directly into surface waters. In highly developed areas, such as in Seattle, Washington (above left), only 15 percent of rain water has the opportunity to soak into the ground.

Contrast this to an undeveloped watershed, where vegetation-covered soil soaks up rainfall rather than allowing it to run off the land (Figure 2). Water filters through the soil before reaching the groundwater table or being released slowly into streams. An undeveloped watershed provides clean, safe water.

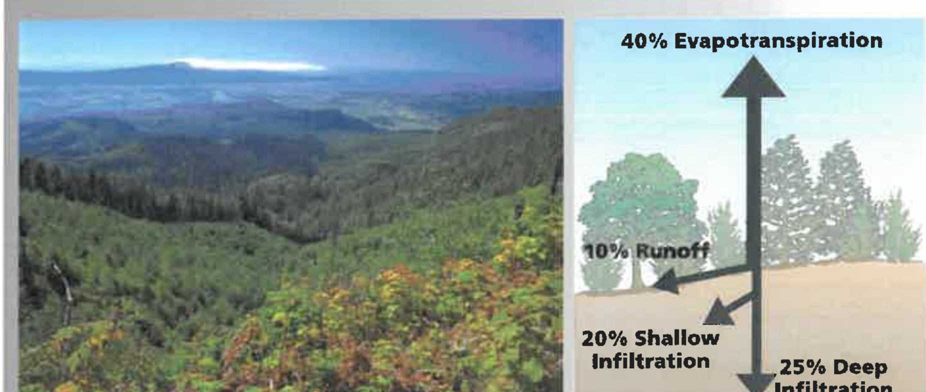

Figure 2. When vegetation and natural areas cover most of the land, such as in Oregon's Upper Tillamook Bay watershed (above left), very little water (only 10 percent) runs off into surface waters. Nearly half of the rainfall soaks into the soil. The remaining water evaporates or is released into the air by vegetation.

Fortunately, by adding LID solutions, communities can help their watersheds act more like undeveloped watersheds—despite the ever-expanding numbers of roads and rooftops. LID practices such as natural or man-made swales, depressions and vegetated areas capture and retain water onsite, allowing time for water to soak into the soil where it is naturally filtered.

LID Provides Many Environmental and Economic Benefits

- **Improved Water Quality**. Stormwater runoff can pick up pollutants such as oil, bacteria, sediments, metals, hydrocarbons and some nutrients from impervious surfaces and discharge these to surface waters. Using LID practices will reduce pollutant-laden stormwater reaching local waters. Better water quality increases property values and lowers government clean-up costs.
- **Reduced Number of Costly Flooding Events.** In communities that rely on ditches and drains to divert runoff to local waterways, flooding can occur when large volumes of stormwater enter surface waters very quickly. Holistically incorporating LID practices reduces the volume and speed of stormwater runoff and decreases costly flooding and property damage.
- **Restored Aquatic Habitat.** Rapidly moving stormwater erodes stream banks and scours stream channels, obliterating habitat for fish and other aquatic life. Using LID practices reduces the amount of stormwater reaching a surface water system and helps to maintain natural stream channel functions and habitat.
- **Improved Groundwater Recharge**. Runoff that is quickly shunted through ditches and drains into surface waters cannot soak into the ground. LID practices retain more rainfall on-site, allowing it to enter the ground and be filtered by soil as it seeps down to the water table.
- **Enhanced Neighborhood Beauty**. Traditional stormwater management infrastructure includes unsightly pipes, outfalls, concrete channels and fenced basins. Using LID broadly can increase property values and enhance communities by making them more beautiful, sustainable and wildlife friendly.

When implemented broadly, LID can also **mitigate the urban heat island effect** (by infiltrating water running off hot pavements and shading and minimizing impervious surfaces), **mitigate climate change** (by sequestering carbon in plants), **save energy** (from green roofs, tree shading, and reduced/ avoided water treatment costs), **reduce air pollution** (by avoiding power plant emissions and reducing ground-level ozone), **increase property values** (by improving neighborhood aesthetics and connecting the built and natural environments), and **increase groundwater recharge**, potentially slowing or reversing land and well field subsidence.

LID Techniques Can Be Applied at Any Development Stage

- **In undeveloped areas, a holistic LID design can be incorporated in the early planning stages**. Typical new construction LID techniques include protecting open spaces and natural areas such as wetlands, installing bioretention areas (vegetated depressions) and reducing the amount of pavement.
- **In developed areas, communities can add LID practices to provide benefits and solve problems**. Typical post-development LID practices range from directing roof drainage to an attractive rain garden to completely retrofitting streets with features that capture and infiltrate rainwater.

A landscaped curb extension calms traffic and captures and infiltrates street runoff in Portland, Oregon.

Rainfall soaks through permeable pavement and into the ground below in this parking area in west Des Moines, Iowa.

Street runoff collects in stormwater planters in Portland, Oregon.

United States Environmental Protection Agency • Office of Wetlands, Oceans, and Watersheds
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EPA 841-N-12-003A • March 2012

Aesthetics of Low Impact Development

LID Technologies Can Benefit Your Community's Visual Environment

LID Barrier Busters Fact Sheet Series

Low Impact Development (LID) Practices Add Natural Beauty

LID practices, which emphasize using natural vegetation to control stormwater, add value and beauty to public and private spaces. LID practices such as bioswales, rain gardens and street trees intercept stormwater, providing water quality benefits and saving money by reducing the need for stormwater conveyance and treatment infrastructure.

LID practices also generate numerous aesthetic and social benefits, including:

- Adding park-like elements to yards and neighborhoods
- Increasing habitat for bees, birds and butterflies
- Calming street traffic and improving public safety
- Offering recreational opportunities and pedestrian access
- Reducing the urban heat island effect

Many LID practices include traditional landscaping techniques that use mulch, plants and grass. With LID, the landscape serves the double purpose of adding beauty and capturing and filtering stormwater.

Southern California's Elmer Street (at right) was retrofitted to include roadside bioswales that capture and infiltrate stormwater. Before the project, neighborhood homes had grass lawns and minimal landscaping (below). Adding LID practices increased the visual beauty of the neighborhood (below right), provided sidewalks and reduced problems with flooding and standing water.

Elmer Street photos provided by the Los Angeles and San Gabriel Rivers Watershed Council.

FAQ

Isn't LID unattractive?

Barrier Busted!

Communities recognize that LID can enhance aesthetics.

EPA's LID Barrier Busters fact sheet series...helping to overcome misperceptions that can block adoption of LID in your community

A flower-filled rain garden adds welcome color to an Ohio yard.

Stormwater flows through a curb inlet into a bioswale on Elmer Street. The water infiltrates into the soil within a day, preventing breeding mosquitoes.

LID Practices Fit Easily into New and Existing Landscapes

Communities can seamlessly incorporate LID practices into the public's everyday landscapes—adding both beauty and functionality. For example, in a traditional parking lot design, raised curbs typically completely surround vegetated traffic islands and all runoff is shunted into storm drains. By making minor modifications to the design, traffic islands can instead collect and infiltrate stormwater while maintaining the same look as a traditional traffic island. Similar opportunities exist everywhere you look, including:

- The vegetated strip often found between the sidewalk and the street can be modified to collect and treat stormwater.
- Permeable pavements, which look similar to traditional pavements, can be used in the place of sidewalks and some roads.
- Porous pavers can provide a stable surface for parking and allow grass to grow and water to infiltrate.
- Public parks or green spaces can be designed to include grassed swales that slow and infiltrate stormwater.
- Impervious rooftops can be replaced with green roofs, reducing runoff and insulating the buildings beneath.

In this Virginia parking lot, traffic islands are designed with curb-cuts and a porous drainage medium to allow runoff to collect and infiltrate.

Visualizing LID in Your Community

Several publications are available to help you visualize how LID can add natural beauty and stormwater control to your community:

- www.epa.gov/greeninfrastructure
- www.epa.gov/nps/lid/#multimedia
- www.nrdc.org/smartGrowth/visions
- www.werf.org/liveablecommunities/index.htm

In Seattle's High Point neighborhood, roadside bioswales collect and filter stormwater, create a park-like feel and improve pedestrian safety.

Landscaped curb extensions (detail, right) on Northeast Siskiyou Street in Portland, Oregon, are designed to intercept stormwater runoff flowing down the street just before it would have entered the storm drain. The stormwater is redirected through a vegetated area, where it has a chance to infiltrate into the soil. Although a minor change, the curb extensions greatly improve the street's appearance and slow the traffic moving through the neighborhood.

A green roof on Philadelphia's Friends Center captures runoff and insulates the building while adding natural beauty to the cityscape.

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